

---

## The Future of Medical Documentation in Hospital Management: Innovations in AI and Machine Learning

Talal Naji Awad Alerwi <sup>1</sup>, Ahmed Hamed S Aljohani <sup>2</sup>, Khaled Mahal K Alrawily <sup>3</sup>, Althubayani, Ayidh Lafi M <sup>4</sup>, Alsuwat Mastour Mohammed H <sup>5</sup>, Saud Lafi A Alenezi <sup>6</sup>, Ali Hassan Salem Al-Omari <sup>7</sup>, Abdulla Rohil A Alrawaili <sup>8</sup>, Fares Muidh Farhan Alanazi <sup>9</sup>, Manal Rashed Albanagi <sup>10</sup>

- 1- Senior Specialist-Health Administration, Health Surveillance Center at King Fahd Industrial Port, Yanbu, Saudi Arabia
- 2- Senior Specialist-Health Administration, Health Surveillance Center at King Fahd Industrial Port, Yanbu, Saudi Arabia
- 3- Senior Specialist in Hospital Management, Turaif General Hospital, Turaif, Saudi Arabia
- 4- Specialist Health Administration, Health Administration and Community Health, Ministry of Health Branch, Medina, Saudi Arabia
- 5- Health & Hospital Administration Specialist, Maqershnaf Health Center, Health Cluster In Taif, Saudi Arabia
- 6- Medical Records Technician, Prince Abdulaziz bin Musa'ed Hospital - Arar, Saudi Arabia
- 7- Health Administration Technician, Makhwah 2 Primary Health Centre, Al Baha, Saudi Arabia
- 8- Technician-Medical secretary, North Medical Tower at Arar in Saudi Arabia
- 9- Health Information Technician, King Fahad Specialist Hospital, Tabuk, Saudi Arabia
- 10- Health Administration, Medical rehabilitation and Care Hospital - Arar, Saudi Arabia

---

### Abstract:

The future of medical documentation in hospital management is poised for a transformative shift driven by innovations in artificial intelligence (AI) and machine learning. These technologies are enabling healthcare organizations to automate the documentation process, reducing the administrative burden on clinicians and increasing the accuracy of patient records. AI-powered tools can transcribe clinical notes in real-time, analyze vast amounts of data to identify patient trends, and even assist in clinical decision-making. This shift not only enhances efficiency but also improves patient outcomes by ensuring that healthcare providers have easy access to comprehensive and up-to-date patient information. In addition to streamlining documentation, AI and machine learning are revolutionizing data analytics in healthcare. Predictive analytics can help hospitals identify potential health risks among patients, enabling proactive management of chronic diseases and reducing readmission rates. Furthermore, natural language processing (NLP) improves the usability of electronic health records (EHRs), making it easier for healthcare teams to extract meaningful insights from unstructured data. As these technologies continue to evolve, they will not only enhance operational efficiency but also foster a more patient-centric approach to care, ultimately reshaping the landscape of hospital management.

**Keywords:** Medical documentation, hospital management, AI, machine learning, healthcare innovation, automated transcription, clinical decision-making, predictive analytics, electronic health records (EHR), natural language processing (NLP), patient outcomes, data analytics.

---

### Introduction:

As healthcare systems across the globe grapple with the dual pressures of managing increasing patient loads and the demand for enhanced quality of care, the role of medical documentation in hospital management has emerged as a critical area of focus. Efficient and effective medical documentation not only ensures the accuracy of patient records but also

supports clinical decision-making, facilitates research, and promotes communication among healthcare providers. However, the traditional methods of managing this documentation can often be cumbersome, time-consuming, and prone to human error. As we move into an era characterized by rapid technological advancement, particularly in the realms of artificial intelligence (AI) and machine

learning (ML), the future of medical documentation is set to undergo a transformative evolution [1].

The integration of AI and machine learning into medical documentation signifies a paradigm shift in how hospitals manage patient data. These innovations promise to address several longstanding challenges within the healthcare sector, including inefficiencies related to time-consuming paperwork, the risk of miscommunication among clinical staff, and concerns regarding data integrity and security. By automating routine documentation processes, AI can enable healthcare providers to focus on what they do best—delivering quality patient care. For instance, natural language processing (NLP), a subset of AI, allows for the conversion of physicians' verbal interactions with patients into structured documentation automatically. This capability not only accelerates the documentation process but also enhances the accuracy and comprehensiveness of patient records [2].

Moreover, machine learning offers the potential to augment clinical decision-making through predictive analytics. By analyzing vast datasets, machine learning algorithms can identify patterns and trends that would be impossible for human practitioners to recognize alone. This capability allows for more personalized patient care as healthcare providers can anticipate patient needs based on historical data. The implementation of AI-driven predictive models can also facilitate proactive interventions, reducing the likelihood of hospital readmissions and improving overall patient outcomes. For instance, using machine learning algorithms to analyze patient demographics, medical history, and social determinants of health can assist hospital management in identifying high-risk patients who may benefit from tailored care plans [3].

In addition to enhancing clinical workflows, AI and machine learning have significant implications for compliance and regulatory requirements in hospital management. With an ever-increasing emphasis on maintaining accurate documentation to meet legal and reimbursement standards, the automation of these processes can help mitigate the risks associated with human error. For example, AI systems can perform real-time monitoring and auditing of medical records to ensure compliance with the latest regulations while flagging any inconsistencies or potential errors. This proactive approach not only safeguards against financial penalties but also fosters a culture of accountability

and transparency within healthcare organizations [4].

The future of medical documentation also raises important ethical and privacy considerations, particularly as healthcare institutions increasingly rely on AI and machine learning solutions. The sensitivity of medical data necessitates stringent measures to protect patient privacy, and the integration of these technologies must be approached with caution. Issues such as data ownership, informed consent, and algorithmic bias emerge as critical areas of scrutiny that require careful consideration from hospital management. In this regard, it is imperative for healthcare organizations to establish robust governance frameworks that align technological advancements with ethical practices [5].

As we transition into this new era of medical documentation, ongoing research and development will play a pivotal role in refining these technologies and ensuring their effectiveness in real-world settings. Collaborative efforts between technology providers, healthcare professionals, and policymakers will be essential in creating standardized protocols and best practices that maximize the potential of AI and machine learning in hospital management. Furthermore, educational initiatives aimed at equipping healthcare providers with the skills needed to leverage these innovative tools will be critical to their successful implementation [6].

### **The Role of AI in Enhancing Documentation Processes:**

In recent years, the integration of artificial intelligence (AI) into various sectors has transformed traditional practices into more efficient and streamlined processes. One of the most significant areas benefiting from this technological advancement is hospital management, particularly in the realm of documentation. The adequate and efficient documentation of patient records, treatment protocols, and administrative processes is crucial for facilitating high-quality patient care, adhering to regulatory standards, and ensuring operational efficiency [7].

Documentation in hospitals serves multiple purposes, ranging from legal compliance and accurate patient care records to billing and operational workflows. It encompasses clinical notes, medical histories, treatment plans, discharge summaries, and more. The traditional methods of

documentation often involve an extensive amount of manual data entry and paper-based records, leading to inefficiencies, errors, and difficulties in information retrieval. The growing volume of healthcare data necessitates a transition to more advanced solutions that can keep pace with the increasing demands of both clinical and administrative processes [7].

### **Applications of Artificial Intelligence in Documentation**

AI technologies are being employed in various capacities to streamline and enhance hospital documentation processes. Some of the most notable applications include:

1. **Natural Language Processing (NLP):**  
NLP enables computational understanding and interpretation of human language. In the context of medical documentation, NLP tools can analyze spoken notes and transcribe them into structured electronic health records (EHRs). This technology can not only help clinicians save time but also improve the accuracy of recorded information by minimizing misinterpretations that often arise during manual transcription [8].
2. **Automated Data Capture:**  
AI can facilitate automated data capture using techniques like optical character recognition (OCR) to digitize paper records. For instance, admission forms and lab results that are still in physical formats can be transformed into digital data the system can use. This helps in maintaining comprehensive records, decreasing the likelihood of data loss, and optimizing storage [9].
3. **Smart Clinical Decision Support:**  
AI algorithms can analyze vast amounts of patient data to provide insights that assist healthcare professionals in making informed decisions. By synthesizing documentation, treatment protocols, and relevant patient histories, AI can provide alerts and suggestions, improving both clinical documentation and patient outcomes.
4. **Predictive Analytics:**  
Predictive analytics, powered by AI, can analyze historical documentation data to

anticipate future healthcare needs. For example, hospitals can utilize AI to predict patient admission rates based on seasonal trends or demographic changes, allowing for better resource allocation and staff planning.

### **5. Quality Assurance and Compliance Monitoring:**

AI systems can automatically monitor documentation processes for compliance with healthcare regulations and standards. By reviewing medical records for completeness and accuracy, AI tools can flag potential omissions or inconsistencies, thereby enhancing the quality of documentation while safeguarding hospitals against legal issues [9].

### **Benefits of AI-Enhanced Documentation**

The incorporation of AI into hospital documentation processes offers numerous benefits that have a profound impact on both operational effectiveness and patient care:

1. **Enhanced Efficiency:**  
By automating routine documentation tasks, healthcare professionals can focus more on patient interactions rather than administrative overhead. This not only enhances efficiency in documentation processes but also optimizes time management and resource utilization in clinical settings [10].
2. **Improved Accuracy:**  
The sophistication of AI algorithms significantly reduces human error associated with manual data entry. As a result, the accuracy of patient records is greatly enhanced, leading to more reliable documentation and better-informed clinical decisions.
3. **Increased Accessibility:**  
AI-driven documentation facilitates better access to patient records for healthcare providers. With the ability to organize and retrieve information seamlessly, clinicians can obtain critical data faster, leading to timely intervention and improved patient outcomes [10].
4. **Cost Reduction:**  
The reduction of manual workloads, errors, and delays streamlines the documentation

process, leading to lower operational costs. Hospitals can allocate resources more effectively by minimizing the time and labor involved in traditional documentation methods.

5. **Enhanced Patient Experiences:** With AI freeing up time for healthcare staff and improving the quality of care documentation, patients benefit from more personalized and responsive healthcare services. This translates into a more satisfying overall experience, which is essential in today's patient-centered care models [10].

### Challenges in Implementing AI

While the benefits of AI in enhancing documentation processes are clear, several challenges must be addressed for its successful implementation:

1. **Integration with Existing Systems:** Many hospitals still rely on legacy documentation systems that may not be compatible with AI solutions. A smooth transition to AI-integrated systems often requires extensive investments in new infrastructure and training [11].
2. **Data Privacy and Security:** The handling of sensitive patient information necessitates rigorous data privacy standards. Ensuring that AI systems comply with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) is paramount to mitigate risks associated with data breaches.
3. **Resistance to Change:** Healthcare professionals may resist adopting AI technologies due to apprehensions about job displacement or unfamiliarity with new systems. Overcoming this inertia requires effective change management strategies and ongoing education about the role of AI in enhancing, rather than replacing, human workload.
4. **Bias in Algorithms:** AI models are only as good as the data used to train them. If historical health records contain biases, the algorithms may perpetuate or even exacerbate these

inequalities in healthcare delivery. It is critical to continuously refine AI systems to ensure fairness and representational equity across diverse patient populations [11].

### The Future of AI in Hospital Documentation

As the healthcare landscape continues to evolve, the role of AI in hospital documentation processes is poised for significant growth. Future innovations may include more sophisticated AI-driven voice recognition technologies, further integration of machine learning algorithms for better predictive analytics, and the development of comprehensive AI platforms that encompass all aspects of hospital management [12].

In addition, global healthcare trends towards personalized medicine and telehealth present new opportunities for AI to enhance documentation. The increased reliance on remote patient monitoring and virtual consultations is likely to demand even more advanced—and flexible—documentation solutions that can seamlessly integrate disparate data sources.

The ongoing research and investment in AI technologies will lay the foundation for revolutionizing how hospitals manage their documentation processes, driving improvements in efficiency, compliance, and patient outcomes [12].

### Machine Learning Applications in Clinical Data Management:

The healthcare sector is undergoing a monumental transformation driven by advancements in technology. Among these innovations, machine learning (ML) stands out as a powerful tool that enhances clinical data management in hospital administration. By leveraging vast amounts of data generated in healthcare settings, machine learning algorithms are able to provide insights that improve patient care, streamline operations, and optimize resources [13].

One of the most significant applications of machine learning in clinical data management is in the optimization of patient treatment plans. Hospitals collect a substantial volume of clinical data, including medical histories, laboratory results, imaging studies, and treatment outcomes. Machine learning algorithms can analyze this data to identify patterns and trends that are not readily observable to human clinicians. For instance, ML models can be trained to predict patient outcomes based on historical data, allowing healthcare providers to

customize treatment plans better suited for individual patients [13].

A prime example of this is the use of predictive modeling in oncology. Machine learning algorithms can analyze extensive datasets that include genomic information, treatment responses, and patient demographics to determine the most effective therapeutic approaches for specific cancer types. This personalized medicine concept can lead to more effective treatments, reduced side effects, and improved survival rates.

Administrative tasks in hospitals often consume valuable resources and time that could be spent on patient care. Machine learning can help automate many of these processes, leading to enhanced operational efficiency. For instance, ML algorithms can be used to automate appointment scheduling and patient flow management. By analyzing historical appointment data, these algorithms can predict patient no-shows and help in optimizing schedules to reduce wait times and improve service delivery [14].

Additionally, machine learning models can enhance billing processes by streamlining claims management and reducing claim denials. By examining various factors associated with successful claims submissions, algorithms can identify red flags or inconsistencies in medical coding that may lead to denials. This not only accelerates revenue cycle management but also reduces administrative overhead.

Resource allocation is a critical aspect of hospital administration, where effective management can significantly impact patient care and hospital profitability. Machine learning models can analyze various data sources, including historical patient admission rates, seasonal illnesses, and local demographics, to make predictions about future resource needs. For instance, hospitals can predict patient volume during flu season or higher admission rates in certain geographical locations, allowing them to allocate staff and equip resources proactively [15].

Furthermore, in emergency departments (ED), machine learning can optimize resource allocation by predicting peak hours and patient inflow. By analyzing past data, algorithms can identify patterns in patient visits that allow hospitals to prepare adequately for surges in patient numbers, thereby ensuring that adequate staff and resources are available during critical times.

In an era dominated by data breaches and privacy concerns, machine learning has emerged as a crucial tool for enhancing data security in clinical data management. By employing ML algorithms, hospitals can continuously monitor their systems for any suspicious activities or anomalies. Machine learning techniques can identify unusual access patterns, such as logins at odd hours or data access attempts from unverified devices, thereby ensuring the security of sensitive patient information [16].

Moreover, machine learning can support hospitals in ensuring compliance with healthcare regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States. By analyzing compliance data and identifying potential violations, machine learning algorithms can provide alerts and recommendations for corrective actions, which helps to mitigate legal risks and enhances accountability in clinical operations.

The healthcare environment is inherently risky, with various factors contributing to potential pitfalls in patient care. Machine learning can significantly aid in risk management by predicting adverse events through the analysis of clinical data. For instance, algorithms can analyze patient data to identify those at high risk of hospital-acquired infections, readmissions, or medication errors. By flagging these patients, healthcare providers can take preventive measures that improve patient safety and reduce unnecessary healthcare costs [17].

Additionally, machine learning can drive quality improvement initiatives. By evaluating clinical workflows and identifying inefficiencies, these algorithms can suggest best practices and process modifications that lead to enhanced patient outcomes. For example, analyzing data on surgical procedures can reveal inconsistencies in practice patterns or highlight variations in recovery times, prompting hospitals to adjust protocols and training [18].

### **Impact of Real-Time Documentation on Patient Care:**

In the rapidly evolving landscape of healthcare, the integration of technology has transformed the way patient care is delivered. One of the most significant advancements in this domain is the implementation of real-time documentation systems, which allow healthcare professionals to record patient information as it happens. This shift from traditional, retrospective documentation to real-time

data entry has profound implications for patient care, influencing clinical outcomes, operational efficiency, and the overall patient experience [19].

One of the primary advantages of real-time documentation is its ability to enhance clinical decision-making. When healthcare providers document patient information in real time, they create a more accurate and comprehensive record of the patient's condition, treatment, and responses. This immediacy allows clinicians to access up-to-date information quickly, facilitating timely interventions and reducing the risk of errors. For instance, in emergency situations, the ability to instantly document and retrieve patient histories, allergies, and medication lists can be life-saving.

Moreover, real-time documentation supports better communication among healthcare teams. With instant access to patient data, interdisciplinary teams can collaborate more effectively, ensuring that everyone involved in a patient's care is on the same page. This collaborative approach not only improves the quality of care but also fosters a culture of accountability and shared responsibility among healthcare providers [20].

Patient safety is a paramount concern in healthcare, and real-time documentation plays a crucial role in mitigating risks associated with medical errors. Traditional documentation methods often lead to discrepancies in patient records, as information may be lost or miscommunicated during transitions of care. Real-time systems minimize these risks by ensuring that data is consistently updated and readily available to all members of the healthcare team.

For example, electronic health records (EHRs) that support real-time documentation can alert clinicians to potential drug interactions or allergies at the point of care, thereby preventing adverse events. Additionally, the use of standardized templates and checklists within real-time documentation systems can further enhance safety by ensuring that critical information is not overlooked during patient assessments and treatment planning [20].

The implementation of real-time documentation also streamlines workflow and enhances operational efficiency within healthcare settings. Traditional documentation processes often involve time-consuming tasks such as handwriting notes, transcribing information, and searching for historical data. In contrast, real-time documentation systems automate many of these processes, allowing

healthcare providers to focus more on patient care rather than administrative duties.

By reducing the time spent on documentation, clinicians can allocate more time to direct patient interaction, which is crucial for establishing rapport and trust. Furthermore, improved efficiency in documentation can lead to shorter patient wait times, increased patient throughput, and ultimately, a more responsive healthcare environment. This efficiency is particularly vital in high-pressure settings, such as emergency departments, where every second counts [20].

Real-time documentation also has a significant impact on patient engagement and satisfaction. When healthcare providers document information in front of patients, it fosters transparency and inclusivity in the care process. Patients are more likely to feel involved in their own care when they can see their information being recorded and discussed in real time. This engagement can lead to increased patient understanding of their health conditions, treatment options, and the rationale behind clinical decisions [21].

Moreover, many real-time documentation systems allow for patient portals, where individuals can access their health information, test results, and treatment plans. This accessibility empowers patients to take an active role in their own healthcare, promoting adherence to treatment regimens and encouraging proactive health management. As a result, patient satisfaction scores often improve, as individuals feel more valued and respected within the healthcare system.

Despite the numerous benefits associated with real-time documentation, there are also challenges that must be addressed to maximize its effectiveness. One major concern is the potential for technology-related burnout among healthcare providers. The pressure to document in real time can lead to increased screen time and distractions, detracting from face-to-face patient interactions. To mitigate this issue, healthcare organizations must prioritize user-friendly interfaces and provide adequate training and support for staff [22].

Additionally, the implementation of real-time documentation systems requires substantial investment in technology and infrastructure. Smaller healthcare facilities may struggle to adopt these systems due to financial constraints or lack of technical expertise. Policymakers and healthcare leaders must work collaboratively to ensure that all

healthcare providers, regardless of size or resources, have access to the tools necessary for effective real-time documentation.

Looking ahead, the future of real-time documentation in patient care is promising. As technology continues to advance, we can expect to see even more sophisticated documentation systems that leverage artificial intelligence (AI) and machine learning to enhance clinical workflows. For instance, AI-driven tools could assist in automatically populating patient records based on voice recognition or predictive analytics, further reducing the burden of documentation on healthcare providers [23].

Moreover, the integration of real-time documentation with telemedicine platforms is likely to become increasingly common, enabling healthcare providers to document virtual visits seamlessly. This integration will be essential as telehealth continues to grow in popularity, particularly in the wake of the COVID-19 pandemic.

#### **Predictive Analytics: Anticipating Patient Needs through Data:**

In the ever-evolving landscape of healthcare, the ability to anticipate patient needs has emerged as a critical driver of improved outcomes, operational efficiency, and enhanced patient experience. Predictive analytics has become a pivotal tool in this quest, employing sophisticated algorithms and machine learning techniques to analyze vast datasets, identify patterns, and make informed predictions about future events. By harnessing the power of predictive analytics, healthcare providers can proactively address patient needs, tailor interventions, enhance resource allocation, and ultimately transform the way care is delivered [24].

At its core, predictive analytics involves the use of statistical algorithms and machine learning techniques to analyze historical data and identify relationships between variables. This process allows organizations to forecast future outcomes based on the patterns discovered in past data. In healthcare, predictive analytics can utilize a wide range of information, including electronic health records (EHRs), demographic data, clinical data, and social determinants of health, among others. The insights generated from this analysis provide a framework for anticipating patient needs, ultimately leading to more personalized and efficient care [25].

#### **Areas of Application**

1. **Chronic Disease Management:** One of the most significant applications of predictive analytics in healthcare is in the management of chronic diseases. Conditions such as diabetes, heart disease, and asthma often require ongoing monitoring and intervention. By analyzing patient data, predictive analytics can identify individuals at high risk for deteriorating health or hospital readmission. For instance, algorithms can flag patients who exhibit certain risk factors—such as non-adherence to medication or missed appointments—prompting healthcare providers to reach out proactively to offer support and resources [26].
2. **Patient Readmission Prevention:** Hospital readmissions are a major challenge in healthcare, often leading to increased costs and poorer patient outcomes. Predictive models can analyze factors such as previous hospitalization history, comorbidities, and social factors to identify patients at high risk for readmission. Armed with this information, healthcare providers can implement targeted interventions, such as enhanced discharge planning, follow-up appointments, or connecting patients with community resources to ensure ongoing support.
3. **Emergency Department Operations:** Predictive analytics can optimize emergency department operations by anticipating patient volumes and resource needs. By analyzing historical visit patterns, seasonal trends, and socioeconomic factors, healthcare organizations can forecast peak times and adjust staffing or resources accordingly. This not only improves patient flow and reduces wait times but also ensures that emergency departments are adequately equipped to handle surges in patient demand [26].
4. **Personalized Treatment Plans:** In the realm of precision medicine, predictive analytics can play a vital role in developing personalized treatment plans based on individual patient data. By analyzing

genetic information alongside medical history and lifestyle factors, healthcare providers can identify which treatments are likely to be most effective for specific patients. This approach not only enhances the efficacy of treatments but also minimizes adverse reactions and unnecessary interventions.

5. **Mental Health Interventions:** Predictive analytics is also making strides in the area of mental health. By analyzing patient behavior patterns, survey responses, and historical treatment data, healthcare providers can identify individuals who may be at risk for mental health crises. This proactive approach allows for early intervention and support, improving patient outcomes and reducing the likelihood of hospitalizations [26].

### Challenges and Considerations

Despite the enormous potential of predictive analytics in healthcare, several challenges must be addressed to maximize its effectiveness. Data privacy and security are paramount concerns, especially when dealing with sensitive patient information. Healthcare organizations must ensure compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) while employing robust safeguards to protect patient data [27].

Moreover, the quality and completeness of data are crucial for predictive analytics to yield reliable results. Inaccurate or biased data can lead to erroneous predictions and potentially harmful healthcare decisions. Therefore, investing in data collection, integration, and standardization is essential to build effective predictive models.

Additionally, providers must recognize that predictive analytics is not a replacement for clinician expertise. While algorithms can process data at impressive speeds, human insight and judgment remain irreplaceable in interpreting results and making clinical decisions. A successful integration of predictive analytics into healthcare must prioritize collaboration between data scientists and healthcare professionals to ensure that insights effectively translate into meaningful interventions [27].

### Future Directions

As technology continues to advance, the future of predictive analytics in healthcare appears promising. The integration of artificial intelligence (AI) and machine learning with predictive analytics holds great potential for enhancing the accuracy and utility of models. In particular, natural language processing (NLP) can extract valuable insights from unstructured data, such as clinical notes and patient feedback.

Moreover, the growth of wearable technologies and remote monitoring devices presents new opportunities for real-time data collection and analysis. Predictive analytics can leverage continuous streams of data from these devices, allowing healthcare providers to anticipate patient needs and intervene promptly outside traditional care settings.

The collaboration between healthcare organizations and technology companies will be vital in shaping the next generation of predictive analytics. As best practices continue to emerge and evolve, organizations must prioritize training and education for healthcare professionals to ensure they are equipped to leverage predictive insights effectively [28].

### Natural Language Processing: Bridging the Gap between Text and Insights:

The healthcare industry is witnessing a seismic shift toward data-driven decision-making, spurred by technological advancements and the exponential growth of available information. Among the most promising innovations transforming this landscape is Natural Language Processing (NLP). With the ability to analyze and interpret vast amounts of unstructured text data, NLP is helping to bridge the gap between raw text and actionable insights, particularly in hospital management.

Natural Language Processing is a branch of artificial intelligence (AI) that enables machines to understand, interpret, and respond to human language in a valuable way. It combines linguistics, computer science, and machine learning to process and analyze large volumes of textual data. At its core, NLP encompasses various tasks such as tokenization, named entity recognition, sentiment analysis, and text classification, among others. By converting unstructured data—like patient notes, discharge summaries, and medical literature—into structured formats, NLP allows healthcare professionals to extract meaningful patterns and



insights that can enhance hospital management practices [29].

### **Applications of NLP in Hospital Management**

#### **1. Improving Patient Care through Enhanced Communication**

One of the most direct applications of NLP in hospital management is in improving patient relations and care. NLP-powered chatbots can engage with patients, answering queries regarding symptoms, medications, and appointment management. This not only alleviates the burden on healthcare staff but also ensures that patients receive prompt and accurate information. Furthermore, by analyzing patient communications and feedback, hospitals can understand patient sentiments, preferences, and pain points, which can inform quality improvement initiatives and enhance the overall patient experience [30].

#### **2. Clinical Documentation and Workflow Optimization**

Clinical documentation is a significant aspect of hospital management that often becomes cumbersome, leading to inefficiencies. NLP can streamline this process by automatically transcribing and structuring physician dictated notes, lab results, and treatment plans into organized databases. This can optimize workflows and reduce administrative burdens, allowing healthcare providers to spend more time on patient care rather than paperwork. Additionally, NLP can assist in identifying missing or incomplete documentation by flagging inconsistencies, leading to more comprehensive patient records [30].

#### **3. Data-Driven Decision-Making**

Hospital management relies heavily on data analytics to inform strategic decisions. NLP enables the extraction of insights from extensive datasets, including clinical trials, academic research, or even social media conversations about healthcare. By analyzing such unstructured text data, hospital administrators can identify emerging trends, assess the effectiveness of healthcare programs, and refine operational strategies. This leads to informed decisions regarding resource allocation, staffing, and

the implementation of innovative healthcare solutions [31].

#### **4. Predictive Analytics and Risk Management**

Another critical application of NLP is in predictive analytics, where insights derived from textual data can identify potential risks, such as patient readmissions or outbreaks of diseases. By processing electronic health records (EHRs), NLP can identify key risk factors and predict adverse events, enabling healthcare professionals to intervene proactively. For instance, analyzing discharge summaries, transfer notes, and other clinical documentation can reveal patterns that might indicate a patient's likelihood of being readmitted, allowing for targeted follow-up care.

#### **5. Regulatory Compliance and Reporting**

Hospitals must adhere to numerous regulations and reporting requirements, which often involve detailed documentation. NLP can assist in ensuring compliance by automating the extraction of necessary information from texts and preparing reports. Moreover, by keeping abreast of new regulations, NLP systems can alert administrators to potential compliance issues, thereby mitigating legal risks associated with documentation errors [32].

### **Challenges of Implementing NLP in Healthcare**

Despite its promising potential, there are several challenges to effectively implementing NLP in hospital management.

#### **1. Data Privacy and Security**

Healthcare data is highly sensitive, governed by regulations such as HIPAA in the United States. The use of NLP must ensure that patient confidentiality and data security are upheld, which can complicate the implementation process and require robust security protocols [33].

#### **2. Integration with Existing Systems**

Many hospitals use legacy systems that may not be compatible with modern NLP solutions. Integrating new technologies with existing electronic health records and

other software solutions can be challenging and resource-intensive.

### 3. **Quality of Data**

NLP algorithms rely on the quality of input data. In healthcare, unstructured data can be noisy, with variations in terminology, abbreviations, and contextual meanings that can lead to inaccuracies. Ensuring high-quality, standardized text input is critical for effective NLP application [33].

### 4. **Interpretation Challenges**

The medical field is laden with jargon and specialized terminologies. While NLP systems are improving, their ability to accurately interpret and contextualize clinical language remains an ongoing challenge, necessitating continual refinement and training of models on clinical datasets [34].

## **The Future of NLP in Hospital Management**

As technology evolves, the future of NLP in hospital management looks promising. With advancements in machine learning and deep learning, we can expect more sophisticated NLP models that possess enhanced understanding and context recognition capabilities. Furthermore, we will likely see increased collaboration across disciplines, as healthcare providers work with data scientists and language specialists to create tailored NLP solutions [35].

## **Challenges and Ethical Considerations in AI-Driven Documentation:**

The rapid advancement of artificial intelligence (AI) technologies has led to their widespread adoption across various sectors, notably in healthcare. AI-based documentation has emerged as a potent tool in hospital management systems, offering the potential to enhance efficiency, accuracy, and patient outcomes. However, the integration of AI in this domain is not without its challenges and ethical considerations [36].

Before delving into the challenges and ethical considerations, it is essential to understand the role of AI in hospital management. AI-based documentation systems automate the process of recording patient data, clinical notes, and treatment plans. These systems employ natural language processing (NLP), machine learning algorithms, and predictive analytics to streamline workflows. By doing so, they aim to minimize administrative

burdens, optimize resource allocation, and improve patient care by ensuring timely and precise documentation.

The potential benefits of AI in hospital management are vast, including reduced human error, enhanced data accessibility, and improved patient-provider communication. However, the adoption of AI-powered documentation systems also introduces various challenges that must be navigated thoughtfully [36].

## **Challenges in AI-Based Documentation**

### 1. **Data Quality and Integrity:**

One of the primary challenges in implementing AI for documentation is the quality and integrity of the data being used. AI systems rely heavily on large datasets for training, and any inaccuracies or biases present in the input data can lead to flawed outputs. In the context of healthcare, where patient data is sensitive and critical, the stakes are particularly high. Poor data quality can result in misdiagnoses, inappropriate treatments, and ultimately, adverse patient outcomes. Ensuring that the data used for training AI systems is accurate, representative, and up-to-date remains a significant hurdle [37].

### 2. **Interoperability Issues:**

Many hospitals utilize a patchwork of electronic health record (EHR) systems, which can lack interoperability. AI-based documentation systems must be able to work seamlessly with existing EHRs to be truly effective. The failure to achieve interoperability can lead to fragmented data management, causing inefficiencies and hindering patient care [38]. Addressing these interoperability challenges requires collaboration between technology vendors and healthcare providers, as well as adherence to industry standards.

### 3. **Resistance to Change:**

Introducing AI-based documentation systems often meets with resistance from healthcare professionals. Many practitioners may be skeptical of replacing traditional documentation methods with automated systems, fearing that the human touch will be lost or that AI may misinterpret nuanced clinical information. Moreover, staff may harbor concerns over

job displacement, despite evidence suggesting that AI is meant to augment rather than replace human roles. Overcoming this resistance necessitates robust change management strategies, ongoing training, and effective communication about the potential benefits of AI integration [39].

4. **Regulatory and Compliance Issues:** The healthcare sector is heavily regulated, and the introduction of AI technologies is subject to myriad legal and compliance considerations. Ensuring compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States is paramount, as these laws safeguard patient privacy and data security. Additionally, AI systems must undergo rigorous validation to ensure they meet clinical standards, which can be a lengthy and resource-intensive process. Navigating the regulatory landscape presents a significant challenge for healthcare organizations aiming to leverage AI technologies [40].

### Ethical Considerations

As AI technologies are implemented in hospital management, several ethical considerations emerge, prompting a need for guided frameworks that prioritize ethical practices in AI deployment.

1. **Patient Privacy and Data Security:** The use of AI in healthcare raises numerous concerns regarding patient privacy and data security. AI systems often require access to large volumes of sensitive patient data, creating risks if appropriate safeguards are not put in place. Breaches of this data could lead to significant harm not only to individual patients but also to the healthcare institution's reputation. Ethical frameworks in AI deployment must prioritize strong data governance and robust cybersecurity measures to protect patient information [41].
2. **Bias and Fairness:** AI systems can unintentionally perpetuate existing biases in healthcare. For instance, if an AI system is trained on historical data that reflects healthcare disparities, it may lead to biased decision-making processes. This raises ethical questions about fairness

and equity in patient treatment. To mitigate biases, it is crucial to ensure diverse representation in datasets and continuously audit AI systems for equitable outcomes. Ethical oversight and accountability mechanisms should be instituted to address and rectify bias in AI algorithms. [42]

3. **Informed Consent:** In the context of AI-powered documentation, the notion of informed consent is complicated. Patients typically understand consent in the context of direct medical procedures; however, the intricacies of AI systems and how they utilize data can be opaque. Healthcare organizations must ensure that patients are adequately informed about how their data will be used, the role of AI in their care, and the implications of data sharing. Transparent communication is integral to maintaining trust in the patient-provider relationship and ensuring that ethical standards are upheld [43].
4. **Autonomy and Accountability:** The implementation of AI in hospital management raises questions about clinical autonomy and accountability. While AI can enhance decision-making processes, it may also lead to an overreliance on technology, potentially undermining the physician's judgment. Healthcare providers must be empowered to critically engage with AI systems, retaining their role as decision-makers. Moreover, the issue of accountability must be addressed: if an AI system makes a mistake, it is crucial to establish who is responsible for the consequences. Clear guidelines for accountability and decision-making authority should be articulated to navigate these ethical waters [44].

### Future Trends and Implications for Hospital Management:

The healthcare landscape is undergoing a seismic shift due to rapid advancements in technology, evolving patient expectations, and the need for enhanced efficiency amidst increasing operational costs. As hospitals navigate this dynamic environment, understanding future trends in hospital management becomes critical to delivering high-quality care while ensuring financial sustainability.

### 1. Increased Adoption of Health Information Technology

One of the most significant trends influencing hospital management is the accelerated adoption of health information technology (HIT). Hospital information systems, including electronic health records (EHRs), telemedicine, and patient engagement platforms, are becoming essential tools for enhancing patient care and operational efficiency. The move towards interoperability—where different systems can communicate effectively—allows for more streamlined sharing of patient information, reducing medical errors and improving treatment outcomes [45].

**Implications:** The integration of HIT promises enhanced data analytics capabilities, enabling hospitals to derive meaningful insights from patient data. This will facilitate evidence-based decision-making and personalized care, ultimately elevating the standard of healthcare delivery. However, hospitals must navigate challenges such as data privacy concerns, high implementation costs, and the need for staff training effectively [45].

### 2. Emphasis on Value-Based Care

The transition from volume-based to value-based care represents a paradigm shift in how hospitals are reimbursed for services. The focus is shifting from the number of procedures performed to the quality of care provided. As insurers and government payers increasingly tie reimbursement rates to patient outcomes, hospitals are prioritizing efficiency and quality of care.

**Implications:** This trend necessitates a re-evaluation of operational strategies. Hospitals will need to invest in quality improvement initiatives, engage in care coordination, and prioritize preventive care to enhance patient experiences. Ultimately, organizations that successfully implement value-based care models will likely see improved patient satisfaction, better health outcomes, and greater financial incentives [46].

### 3. Rise of Telehealth and Remote Patient Monitoring

The COVID-19 pandemic has accelerated the adoption of telehealth services, enabling hospitals to provide care remotely. This modality not only enhances access to healthcare for patients in rural or underserved areas but also streamlines treatment for chronic conditions through remote patient monitoring (RPM). The growing acceptance of

telehealth by patients and providers signals a permanent shift in how care is delivered.

**Implications:** Telehealth can reduce hospital readmission rates, increase patient satisfaction, and improve overall resource management. However, hospitals must integrate telehealth into their existing service models thoughtfully. This integration involves developing robust IT infrastructure, training staff, and ensuring compliance with regulations governing telemedicine services. Success in this area can broaden a hospital's reach and diversify revenue streams [47].

### 4. Focus on Operational Efficiency and Cost Management

Rising costs and shrinking margins are pushing hospitals to seek innovative strategies for operational efficiency. Lean management practices, supply chain optimization, and resource allocation strategies are increasingly being prioritized to enhance the bottom line. Hospitals are also leveraging data analytics to identify inefficiencies in workflows and patient flow, ultimately focusing on continuous improvement initiatives [48].

**Implications:** By embracing operational efficiency, hospitals can redirect resources to patient care and innovation rather than administrative overhead. However, a culture of efficiency must be accompanied by strong leadership who can facilitate change and motivate staff through this transition. Additionally, utilizing data analytics responsibly can yield insights while ensuring compliance with healthcare regulations [49].

### 5. Personalized Medicine and Genomics

As advances in genomics and biotechnology progress, the future of hospital management will undoubtedly revolve around personalized medicine. Tailoring treatment plans based on individual genetic profiles can significantly enhance treatment efficacy and patient outcomes. This trend aligns with the broader movement towards precision healthcare, where interventions are more closely matched to patients' unique needs [50].

**Implications:** Hospitals will need to adapt their management practices to support these developments, potentially requiring new personnel with specialized skills in genomics and data analysis. Investment in research and development may also be necessary, positioning hospitals as

leaders in innovative therapies that could fundamentally change treatment paradigms [51].

## 6. Emphasis on Patient-Centered Care

The growing emphasis on patient-centered care reflects a fundamental change in hospital management perspectives, acknowledging the importance of engaging patients in their care journeys. This holistic approach recognizes that healthcare is not merely a transactional process; it involves understanding patients' preferences, needs, and experiences [52].

**Implications:** Hospital management will need to establish mechanisms to gauge patient feedback actively, streamline appointment scheduling, and offer personalized communication. Fostering an organizational culture that prioritizes patient empowerment can enhance loyalty and satisfaction, leading to improved health outcomes and a competitive advantage in the market [53].

## 7. Sustainability and Social Responsibility

In an era where environmental concerns take precedence, hospitals are increasingly adopting sustainable practices. From waste reduction efforts to energy-efficient facilities, sustainability is fast becoming a key concern for hospital management. Hospitals have a unique opportunity to lead by example—promoting health not only through medical treatment but also through social responsibility in their operations [54].

**Implications:** Implementing sustainable practices can yield both cost savings and enhanced public perception. However, hospitals must balance sustainability initiatives with budget constraints, requiring innovative thinking and collaboration with stakeholders to develop effective strategies [55].

## Conclusion:

In conclusion, the future of medical documentation in hospital management is being significantly reshaped by advancements in artificial intelligence and machine learning. These technologies are not just streamlining administrative processes but are also enhancing the quality and accessibility of patient information, ultimately leading to improved patient outcomes and more efficient healthcare delivery. As AI-driven tools automate repetitive documentation tasks and leverage data analytics for predictive insights, healthcare professionals can focus more on patient care rather than paperwork.

However, the integration of these innovations is not without challenges. Issues related to data privacy, accuracy, and the need for robust training in new technologies must be addressed to fully realize their potential. As hospitals embrace these advancements, a concerted effort is required to ensure that ethical considerations are prioritized, fostering an environment where technology complements rather than complicates the clinician-patient relationship. By navigating these challenges, the future of medical documentation can become a powerful ally in the pursuit of excellence in healthcare management.

## References:

1. Chen M, Decary M. Artificial intelligence in healthcare: an essential guide for health leaders. *Health Management Forum*. 2020;33(1):10-18.
2. Budget. Building an innovation economy of the future. Department of Finance Canada; modified 2021 Apr. 19.
3. Jaremko JL, Azar M, Bromwich R. Canadian association of radiologists white paper on ethical and legal issues related to artificial intelligence in radiology. *Can Assoc Radiol J*. 2019;70(2):107-118.
4. Levin S, Toerper M, Hamrock E. Machine-learning-based electronic triage more accurately differentiates patients with respect to clinical outcomes compared with the emergency severity index. *Ann Emerg Med*. 2018;71(5):565-574.
5. Canadian Medical Association. Guiding principles for physicians recommending mobile health applications to patients. Available: 2015. May 30.
6. Verma AA, Murray J, Greiner R, et al. Implementing machine learning in medicine. *Canadian Medical Association Journal*. 2021;193(34):E1351-E1357.
7. *Hollis v. Dow Corning Corp*, 1995. CanLII 55 (SCC), [1995] 4 SCR 634.
8. Canadian Medical Association. CMA policy base. 2021. Jun. 28.
9. Durbin E. Torts – nature of tort law and liability. *West law Canada*. 2021.
10. Price WN, Gerke S, Cohen IG, Cohen IG. Potential liability for physicians using artificial intelligence. *JAMA*. 2019;322(18):1765-66.
11. Allain J. From jeopardy! To jaundice: the medical liability implications of Dr. Watson and other artificial intelligence

- systems. *LA Law Rev.* 2013;73(7):1049-1079.
12. Gulshan, Peng L, Coram M, et al. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *JAMA.* 2016;316(22):2402-2410.
13. MacMahon H, Naidich DP, Goo JM, et al. Guidelines for management of incidental pulmonary nodules detected on CT images: from the Fleischner Society 2017. *Radiology.* 2017;284(1):228-243.
14. *Rylands v. Fletcher*, 1868. UKHL 1, [1868] LR 3 HL 330.
15. Mindshare Medical. Mindshare medical announces Health Canada clearance for nationwide use of RevealAI-Lung product. 2018.
16. Reznick R, Harris K, Horsley T, Sheikh M. Task force report on artificial intelligence and emerging digital technologies. 2020. Feb.
17. Strategy Pan-Canadian AI. Canadian Institute for Advanced Research. 2021. Aug. 8.
18. *Bazley v. Curry*, 1999. CanLII 692 (SCC), [1999] 2 SCR 534.
19. Bathae Y. The artificial intelligence black box and the failure of intent and causation. *Harv J Law Technol.* 2018;31(2):890-938.
20. *Wilson v. Swanson*, 1956. CANLII 1 (SCC). [1956] SCR 804.
21. Canadian Institutes of Health Research. Introduction of Artificial Intelligence and Machine Learning in Medical Devices. 2019. May.
22. Güneş ED, Yaman H, Çekyay B, Verter V. Matching patient and physician preferences in designing a primary care facility network? *J Oper Res Soc.* 2017;65:483–96. doi: 10.1057/jors.2012.71.
23. Esteva A, Kuprel B, Novoa RA, Ko J, Swetter SM, Blau HM, et al. Dermatologist-level classification of skin cancer with deep neural networks. *Nature.* 2017;542:115–8. doi: 10.1038/nature21056.
24. Computer History Museum. Mountain View, California.
25. Caffery L, Clunie D, Curiel-Lewandrowski C, Malvey J, Soyer H, Halpern A. Transforming dermatologic imaging for the digital era: Metadata and standards. *J Digit Imaging.* 2018;31:568–77. doi: 10.1007/s10278-017-0045-8.
26. Hekler A, Utikal J, Enk AH, Hauschild A, Weichenthal M, Maron RC, et al. Superior skin cancer classification by the combination of human and artificial intelligence. *Eur J Cancer.* 2019;120:114–21. doi: 10.1016/j.ejca.2019.07.019.
27. Jing Y, Bian Y, Hu Z, Wang L, Xie X. Deep learning for drug design: An artificial intelligence paradigm for drug discovery in the big data era. *AAPS J.* 2018;20:58. doi: 10.1208/s12248-018-0210-0.
28. McCarthy J, Minsky M, Rochester N, Shannon C. A proposal for the Dartmouth summer research project on artificial intelligence 1956.
29. Turing AM. Computing Machinery and Intelligence. *Mind, New Series.* 1950;59:433–60.
30. Dilsizian S, Siegel E. Artificial intelligence in medicine and cardiac imaging: Harnessing big data and advanced computing to provide personalized medical diagnosis and treatment. *Curr Cardiol Rep.* 2014;16:2014. doi: 10.1007/s11886-013-0441-8.
31. Géron A. Hands-On Machine Learning with Scikit-Learn & Tensor Flow. 1st ed. Sebastopol, CA, USA: O'Reilly; 2017.
32. Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, et al. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *JAMA.* 2016;316:2402–10. doi: 10.1001/jama.2016.17216.
33. Li C, Shen C, Xue K, Shen X, Jing Y, Wang ZY, et al. Artificial intelligence in dermatology: Past, present, and future. *Chinese Med J.* 2019;132:2017–20. doi: 10.1097/CM9.0000000000000372.
34. Ekins S. The next era: Deep learning in pharmaceutical research. *Pharm Res.* 2016;33:2594–603. doi: 10.1007/s11095-016-2029-7.
35. Laura Craft. Emerging Applications of AI for Healthcare Providers GARTNER. 2017.
36. Bogoch L, Watts A, Thomas-Bachli A, Huber C, Kraemer MUG, Khan K. Pneumonia of unknown aetiology in Wuhan, China: Potential for international spread via commercial air travel. *J Travel Med.* 2020;27:2020:taaa008. doi: 10.1093/jtm/taaa008.
37. Eloranta S., Boman M. Predictive models for clinical decision making: Deep dives in practical machine learning. *J. Intern. Med.* 2022;292:278–295. doi: 10.1111/joim.13483.

38. Kaur S., Singla J., Nkenyereye L., Jha S., Prashar D., Joshi G.P., El-Sappagh S., Islam M.S., Islam S.R. Medical diagnostic systems using artificial intelligence (AI) algorithms: Principles and perspectives. *IEEE Access*. 2020;8:228049–228069. doi: 10.1109/ACCESS.2020.3042273.
39. Huang S., Yang J., Fong S., Zhao Q. Artificial intelligence in cancer diagnosis and prognosis: Opportunities and challenges. *Cancer Lett*. 2020;471:61–71. doi: 10.1016/j.canlet.2019.12.007.
40. Davenport T.H. *The AI Advantage: How to Put the Artificial Intelligence Revolution to Work*. MIT Press; Cambridge, MA, USA: 2018.
41. Wang F., Preininger A. AI in health: State of the art, challenges, and future directions. *Yearb. Med. Inform.* 2019;28:16–26. doi: 10.1055/s-0039-1677908.
42. McCorduck P., Cfe C. *Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence*. CRC Press; Boca Raton, FL, USA: 2004.
43. Nezamabadi K., Sardaripour N., Haghi B., Forouzanfar M. Unsupervised ECG analysis: A review. *IEEE Rev. Biomed. Eng.* 2022;16:208–224. doi: 10.1109/RBME.2022.3154893.
44. Bardhan I., Chen H., Karahanna E. Connecting systems, data, and people: A multidisciplinary research roadmap for chronic disease management. *MIS Q.* 2020;44:185–200.
45. Rajpurkar P., Chen E., Banerjee O., Topol E.J. AI in health and medicine. *Nat. Med.* 2022;28:31–38. doi: 10.1038/s41591-021-01614-0.
46. LeCun Y., Bengio Y., Hinton G. Deep learning. *Nature*. 2015;521:436–444. doi: 10.1038/nature14539.
47. Cortez N. *Digital Health: Scaling Healthcare to the World*. Springer; Cham, Switzerland: 2018. pp. 249–269.
48. Hosny A., Parmar C., Quackenbush J., Schwartz L.H., Aerts H.J. Artificial intelligence in radiology. *Nat. Rev. Cancer*. 2018;18:500–510. doi: 10.1038/s41568-018-0016-5.
49. DuBois K.N. Deep medicine: How artificial intelligence can make healthcare human again. *Perspect. Sci. Christ. Faith*. 2019;71:199–201.
50. Coronato A., Naeem M., De Pietro G., Paragliola G. Reinforcement learning for intelligent healthcare applications: A survey. *Artif. Intell. Med.* 2020;109:101964. doi: 10.1016/j.artmed.2020.101964.
51. Kagiya N., Shrestha S., Farjo P.D., Sengupta P.P. Artificial intelligence: Practical primer for clinical research in cardiovascular disease. *J. Am. Heart Assoc.* 2019;8:e012788. doi: 10.1161/JAHA.119.012788.
52. Brynjolfsson E., McAfee A. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. WW Norton & Company; New York, NY, USA: 2014.
53. Waring J., Lindvall C., Umeton R. Automated machine learning: Review of the state-of-the-art and opportunities for healthcare. *Artif. Intell. Med.* 2020;104:101822. doi: 10.1016/j.artmed.2020.101822.
54. Alpaydin E. *Introduction to Machine Learning*. MIT Press; Cambridge, MA, USA: 2020.
55. Guan Z., Li H., Liu R., Cai C., Liu Y., Li J., Wang X., Huang S., Wu L., Liu D. Artificial intelligence in diabetes management: Advancements, opportunities, and challenges. *Cell Rep. Med.* 2023;4:101213. doi: 10.1016/j.xcrm.2023.101213.