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REVIEW

Streamlining Patient Fall Prevention and Management Through Human-Centered AI-Based Decision Support Systems

Firda Rahmadani[1], Fatima Y Alshamsi[2], Balqees Almazrouei[2], Aisha Hanaya Alsuwaidi[2], Mohammed Alhammadi[1], Mecit Can Emre Simsekler[1]

[1]Department of Management Science and Engineering, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates; [2]Centre for Biotechnology, Biomedical Engineering Department, College of Medicine and Health Sciences, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates

Correspondence: Mecit Can Emre Simsekler, Department of Management Science & Engineering, Khalifa University of Science & Technology, P.O. Box 127788, Abu Dhabi, United Arab Emirates, Tel +971 2 312 4058, Fax +971 2 447 2442, Email emre.simsekler@ku.ac.ae

Abstract: Patient falls are a major concern in healthcare due to their impact on patient safety, prolonged hospital stays, and increased costs. Traditional fall prevention methods often lack precision and adaptability, emphasizing the need for predictive approaches. This study reviews the current literature and explores the integration of human-centered artificial intelligence (AI)-based decision support systems to improve fall prevention through proactive risk assessment and prediction. This system enables early identification of fall risks, facilitating personalized interventions and real-time monitoring via advanced sensors and wearable devices. These technologies may provide timely alerts to caregivers and support administrators in optimizing resource allocation. Additionally, this study highlights the importance of systems thinking, recognizing patient falls as outcomes of interconnected system failures. By leveraging causal loop analysis and feedback mechanisms, healthcare stakeholders can develop dynamic, system-wide strategies to enhance fall prevention and operational efficiency.

Keywords: patient safety, patient fall, fall prevention, fall prediction, risk management, human-AI interaction, artificial intelligence, decision support system, system thinking

Introduction

Patient falls represent the most frequently reported adverse events in healthcare settings.[1] Research indicates that patient falls in hospitals affect ~2–17% of patients during their hospital stay.[2] Inpatients with stroke are at a significantly increased risk of falls, with between 14% and 65% falling at least once during their hospital stay.[3] Beyond the commonly recognized groups such as older adults with mobility impairments or balance issues, healthcare providers should also consider other vulnerable populations.[4] Patients experiencing delirium or confusion, whether due to medications, infections, or underlying conditions, are at heightened risk due to disorientation and poor judgment.[5] Post-surgical patients, particularly those recovering from orthopedic or neurological procedures, may have limited mobility, dizziness, or sedation side effects that increase fall risk.[6] Additionally, individuals with a history of falls, impaired vision, or those taking high-risk medications (eg, sedatives, antihypertensives) should be closely monitored.[7] By expanding fall risk assessments to include these diverse patient groups, hospitals can implement targeted interventions to enhance patient safety and reduce preventable falls.

Various strategies have been explored to prevent patient falls, including the development of fall prevention programs tailored to hospital settings. It has been noted that current fall-prevention strategies may not have significantly reduced the number of patient falls, although targeting individual risk factors could be beneficial.[8] Educating patients about fall risk is essential in preventing falls during hospitalization.[9] Understanding the trajectory of hospital fall rates can aid in classifying hospitals based on their fall rate patterns, which can guide interventions to reduce falls.[10]

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Several studies have highlighted the importance of implementing fall prevention programs to address this issue effectively. Wilson et al[11] and Smith et al[12] highlighted the importance of healthcare providers' perceptions and practices in implementing fall prevention interventions tailored to patient-specific risk factors. Quatman et al[13] explored the role of community paramedicine in fall prevention which focused on acute care coordination, including pre-hospital, emergency, and in-hospital transitional care, often involving advanced protocols for patient assessment and intervention. Understanding these factors is crucial for the successful implementation of evidence-based fall prevention strategies.

Despite the importance of preventing falls in hospital settings, current practices have limitations and gaps. Current strategies, including risk assessments, bed alarms, and staff monitoring, have significant limitations that restrict their effectiveness.[14] One major issue is the inconsistency in fall risk assessment tools, as different facilities use varying methods with limited predictive accuracy.[15] Many tools rely on subjective factors rather than real-time data, leading to both overestimation and underestimation of fall risk.[16] Another key challenge is staffing and workflow limitations. Healthcare workers often face high patient-to-nurse ratios, making it difficult to provide constant supervision for at-risk individuals.[17] Alarm fatigue further complicates the issue, as frequent false alerts from bed, delaying responses to actual fall incidents.[18] Many fall prevention measures, such as hourly rounding, are also deprioritized due to competing clinical demands.[19] Furthermore, interventions tend to follow a one-size-fits-all approach rather than addressing individual patient needs, such as cognitive impairments or specific mobility limitations.[20] Without proper patient and family engagement, many individuals remain unaware of their fall risks or how to prevent accidents.[21] Studies have highlighted various barriers to the effective implementation of fall prevention programs, including leadership support, staff engagement, pilot testing, data provision, and staff attitudes.[22] While multifactorial fall prevention interventions have shown effectiveness in reducing falls, their translation into clinical settings has been limited.[23] Nurses play a significant role in fall prevention but face systemic challenges, including excessive documentation, which may restrict proactive risk mitigation.[24] Best practice guidelines recommend strategies such as establishing multidisciplinary teams, conducting fall risk screening, implementing standard fall prevention protocols, and minimizing injuries from falls.[25]

Implementing effective fall prevention and management strategies is crucial to improving patient safety. One approach that has shown promise is using human-centered Artificial Intelligence (AI) decision support systems (DSS) tailored to individual patient needs.[26] These systems involve a three-step process: conducting fall risk assessments, developing tailored fall prevention plans with evidence-based interventions, and consistently implementing these plans. A comprehensive approach like human-centered AI DSS is crucial to enhance patient fall management and prevention, as highlighted in other patient safety contexts as well, such as SEPSIS and AKI.[27,28] Research supports the effectiveness of tailored fall prevention programs using DSS, where providers actively engage patients and families in identifying fall risks.[29] The development of human-centered AI DSS that calculates fall risk and offers evidence-based prevention recommendations based on Electronic Health Records (EHR) and sensor data can assist in effectively identifying and managing fall risks in clinical practice.[30] Moreover, this framework customized for fall prevention management in primary care settings can further improve the efficacy of interventions.[31]

Clinical Process Description and Framework Development

Patient Fall Assessment in Healthcare Settings

When a patient is admitted to a hospital, nurses typically perform a visual assessment to gauge whether an official fall risk test is warranted (see Figure 1). Evidence-based guidelines from organizations like the US Agency for Healthcare Research and Quality (AHRQ) emphasize the importance of clinical practice guidelines to promote evidence-based fall prevention strategies.[32] Hospitals commonly use one of the following standardized tests to assess fall risk: the Morse Fall Scale,[33] the Hendrich II Fall Risk Model,[34] or the Timed Up & Go Test.[35] Following this assessment, patients are assigned a risk score categorized as low, medium, or high risk. Suppose a patient is deemed to have a high fall risk or experiences a fall incident; interventions such as walking aids (eg, canes or walkers) or assistance while walking are provided. For patients undergoing surgery or those whose medication may impact gait, a toileting schedule is often implemented along with the aforementioned walking aids. These measures aim to mitigate the risk of falls and ensure patient safety during their hospital stay.

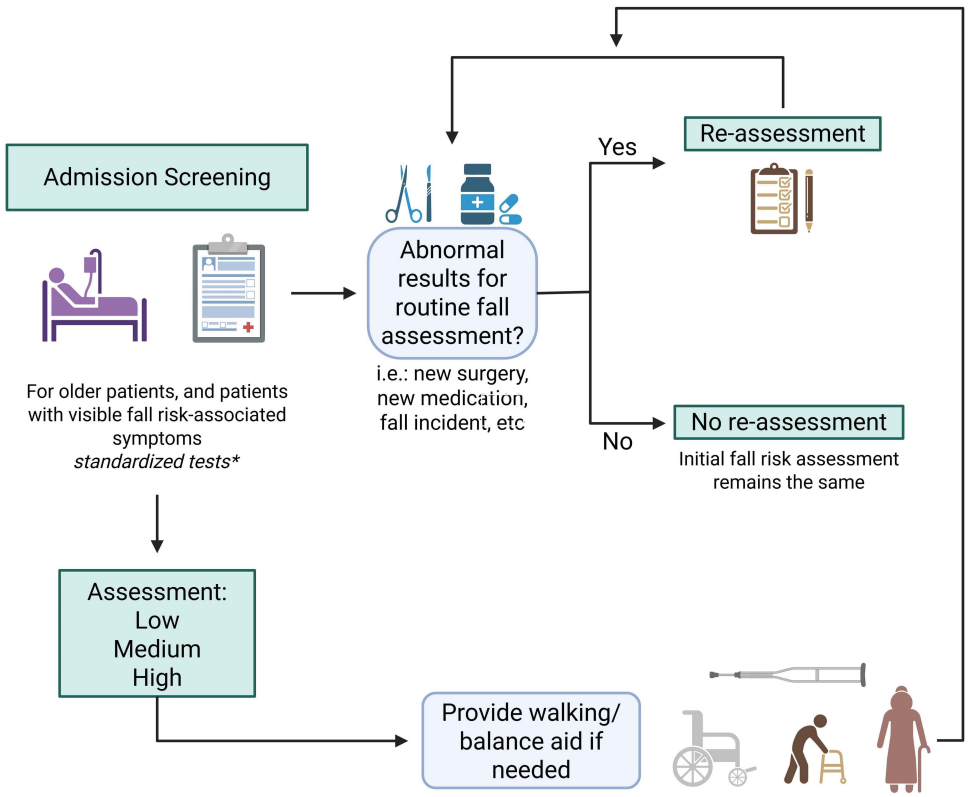

Figure 1 Current Workflow for Assessing Patient Fall Risk in Hospitals. *: Examples of standardized tests: Morse Fall Scale, Hendrich II Fall Risk Model, and Timed Up & Go Test. Created in BioRender. Kannout, H. (2025) https://BioRender.com/o77tmjp.

While the current system provides a framework for fall risk assessment, it has several limitations. The initial visual assessment can be subjective, varying based on the experience and judgment of the healthcare provider.[36] Additionally, the standardized tests used across hospitals lack uniformity, leading to inconsistencies in assessing and managing fall risk.[37] This variability underscores the need for a more standardized and objective fall risk assessment system. Leveraging AI and Machine Learning (ML) technologies could offer a solution by analyzing a wide range of patient data and providing consistent risk assessments. These technologies can also assist in developing tailored interventions, enhancing the effectiveness of fall prevention strategies, and ultimately improving patient outcomes.

Risk Assessment

Risk assessment for patient falls is crucial in ensuring patient safety in healthcare settings. This process involves systematically identifying and evaluating risk factors that increase the likelihood of falls, which can result in severe injuries, prolonged hospital stays, and increased healthcare costs. Key risk factors include patient-related aspects such as age, history of previous falls, mobility impairments, cognitive deficits, and medication usage, particularly those affecting balance and coordination. Environmental factors, like poor lighting, slippery floors, and inadequate handrails, also play a significant role. Based on a fall risk assessment, categorizing patients into high- and low-risk groups is foundational in fall prevention programs.[38] Interventions for fall prevention include universal precautions for all patients and targeted interventions for specific risks.[32] As shown in Table 1, identifying risk factors and implementing evidence-based interventions, such as fall prevention programs tailored to individual patient needs, regular risk reassessments, staff training on fall prevention strategies, and environmental modifications, can significantly reduce the incidence of falls. Additionally, the use of assistive devices, proper footwear, and patient education on fall prevention can further enhance safety. Continuous monitoring and reporting of fall incidents enable healthcare providers to refine and adapt their strategies, ensuring the dynamic management of fall risks in patient care settings.

Table 1 Fall Risk Factors in Literature

Risk Factor	Identified to Be a Fall Risk	Evidence	Mitigation
Clinical factors			
Mobility impairment	[1,2]	Patients who have difficulty walking or transferring themselves independently.	Walking aids, assisted walking, and timed toileting.
Medication side effects	[1–3]	Medications such as sedatives, hypnotics, narcotics, antihypertensives, and psychotropics can cause dizziness and drowsiness.	Communicate fall risk and educate patients about fall alarms in the patient room.
Cognitive impairment	[4]	Dementia or delirium can affect judgment, spatial awareness, and decision-making.	Use more visual aids and involve support workers for supervision.[5] Manage risk factors such as sleep deprivation.[6]
Age	[3,7]	Elderly patients are more prone to falls due to decreased muscle strength, impaired balance, and slower reaction times.	Muscle strengthening exercises combined with balance training[8] and assistive devices.[9] Review anticholinergic medications.[10]
History of falls	[3,11]	Patients who have experienced falls in the past are more likely to fall again.[12]	Communicate fall risk and educate patients about fall alarms in the patient room.
Poor footwear	[13–16]	Ill-fitting or non-slippery footwear can contribute to instability.	Use of proper footwear.
Underlying medical conditions	[17]	Parkinson's disease, stroke, neuropathy, or visual impairment lead to higher fall risk due to impaired motor function or sensory deficits.	Motor dual-tasking training.[18] Balance and mobility training.[19] Executive Function and Cognitive Training[20,21]
Gender	[22]	Women often exhibit a higher risk of falls compared to men due to their greater involvement in housework responsibilities.	Improve home safety: secure rugs, improve lighting, and install grab bars.[23] Educate on safe methods to perform daily tasks (lifting techniques, etc).[24]
Life style	[25]	There is a debate about whether living alone, with a spouse, or with others has an effect on fall.	Employ at-home caretaker, use smart watch for fall detection.
Sleep quality	[26]	Insufficient sleep can impact balance and coordination	Enhance sleep quality through lifestyle modifications, environmental adjustments, and medication.
Organizational factors			
Non-Use of Assistive Devices	[27]	Adults who fell were found not using their assistive device at the time of the fall, despite believing that it helps prevent falls.	Educate patients about the importance of assistive devices.
Inadequate supervision	[28,29]	Patients who require supervision or assistance with mobility but do not receive it. There is a debate about whether it increases or decreases the fall risk.	Emphasize the need for improved knowledge and skills of healthcare providers regarding fall prevention.
Assistive devices	[30–32]	There is a significant association between the use of mobility devices, such as canes, and an increased occurrence of falls.	Ensure that the mobility aids used are appropriate for the individual's condition, correctly fitted, and users are trained to use them safely.
Screening tool (risk level)		Screening tools use scoring to quantify risk; no difference in completed assessments or fall prevention interventions.	

(*Continued*)

Table 1 (Continued).

Risk Factor	Identified to Be a Fall Risk	Evidence	Mitigation
Unclear policies and guidelines	[33]	Hospitals that updated their policies to include comprehensive fall risk assessments and tailored interventions showed a decrease in fall rates.	Implement clear guidelines regarding falls, and educate healthcare workers accordingly.
Communication	[28,34]	Better communication can enhance the management of fall risks, improve reporting procedures, and ensure adherence to care plans.	Improved communication networks among diverse healthcare staff can significantly enhance fall-reduction efforts.[34]
Insufficient or unavailable resources	[2]	Hospitals with higher rates of falls often experience increased resource utilization, including longer hospital stays and higher associated costs.	Adequate staffing, equipment, and environmental safety measures.
Environmental condition	[35]	Hazards within the hospital environment, such as wet floors, inadequate lighting, cluttered walkways, or improper bed height.	Identify and address specific fall risk factors.[36] Conduct safety audits to identify environmental hazards.[37]

Decision Support Framework

To systematically address the complex interactions among people, technology, tasks, environments, and organizational factors in healthcare, various systems engineering approaches have been developed. Among these, the Systems Engineering Initiative for Patient Safety (SEIPS) framework is one of the most widely used for analyzing and enhancing patient safety and quality of care.[39]

SEIPS analysis is a valuable tool for analyzing and improving healthcare systems, enhancing patient safety, and optimizing the work of healthcare professionals and patients (Table 2). It has five components: person, task, technology, organization, and environment.

The person category (P) examines the human elements involved in fall prevention, including the physician's knowledge and perception of AI's role in decision-making, the nurse's eagerness to collaborate with the care team, the patient's understanding of their treatment options, and their guardian's awareness of their condition. These factors underscore the importance of education and communication among all parties involved in the care process. The tasks (T) associated with fall prevention include initial screenings and risk assessments for newly admitted patients, as well as managing the complexity of tasks such as medication choices and their effectiveness. This highlights the critical role of thorough and precise initial evaluations in fall prevention strategies. The technology (Te) focuses on the availability and usability of tools like sensors and portable devices during patient screening and the integration of human-centered AI DSS into the clinical workflow. Effective technology use is essential for timely and accurate risk assessments and interventions. Organizational (O) factors involve the norms and culture surrounding decision-making roles, procedures for patient handling, the prevailing blaming culture in safety cases, and policies about visiting periods for guardians. These elements reflect the broader administrative and cultural context of implementing patient safety measures. The environmental conditions (E) considered include the hospital ward's physical layout, background noise and lighting, and the policies regarding insurance reimbursement. Each of these can significantly influence patient safety and the effectiveness of fall prevention measures. Overall, the SEIPS analysis presented in Table 2 highlights the complexity of factors that must be managed to prevent falls in hospital settings effectively. It suggests that a holistic approach addressing all these dimensions is necessary to improve patient care.

A robust DSS for patient fall prediction can significantly enhance patient safety in healthcare settings, as shown in Figure 2. This system can use sensor data, EHR, treatment, and intervention lists to accurately assess fall risk and provide

Table 2 SEIPS Analysis During Fall Patient's Care in the Hospital

SEIPS Factors	Description
PERSON (P)	
P1 (Physician)	The physician's knowledge and perception of AI in assisting decision making process
P2 (Nurse)	Willingness to collaborate with other care team
P3 (Patient)	The patient's understanding of their treatment option based on their preferences
P4 (Patient's guardian)	The understanding about patient's condition
TASK (T)	
T1	Screening and risk assessment for newly admitted patient
T2	Task complexity, including the number of medication choices and effectiveness for specific patient condition
TECHNOLOGY (Te)	
Te1	Availability of sensor or portable device during patient screening and surveillance
Te2	Usability of DSS embedded in current clinical workflow
ORGANIZATION (O)	
O1	Norms and culture about the physician's and patient's roles during decision-making process
O2	Procedure or guideline during patient handling
O3	Blaming culture related to patient safety-case
O4	Visiting period for patient's guardian
ENVIRONMENT (E)	
E1	The physical layout of ward or specific department where patient is hospitalized
E2	The presence of background noise, room lighting, and interruptions
E3	Insurance policy regarding reimbursement of treatment and medication

tailored recommendations to mitigate the risk. At the system's core are multiple input sources, including wearable sensors and environmental monitoring devices that track real-time gait, balance, and movement patterns. These are combined with EHR data, such as medical history, medications, and previous fall incidents, to create a comprehensive risk profile. The risk assessment module employs AI-driven predictive analytics to evaluate dynamic (real-time) and static (historical) factors, identifying patients with the highest risk of falls. The system leverages a knowledge-based engine that incorporates clinical guidelines, expert recommendations, and systems thinking to ensure interventions are

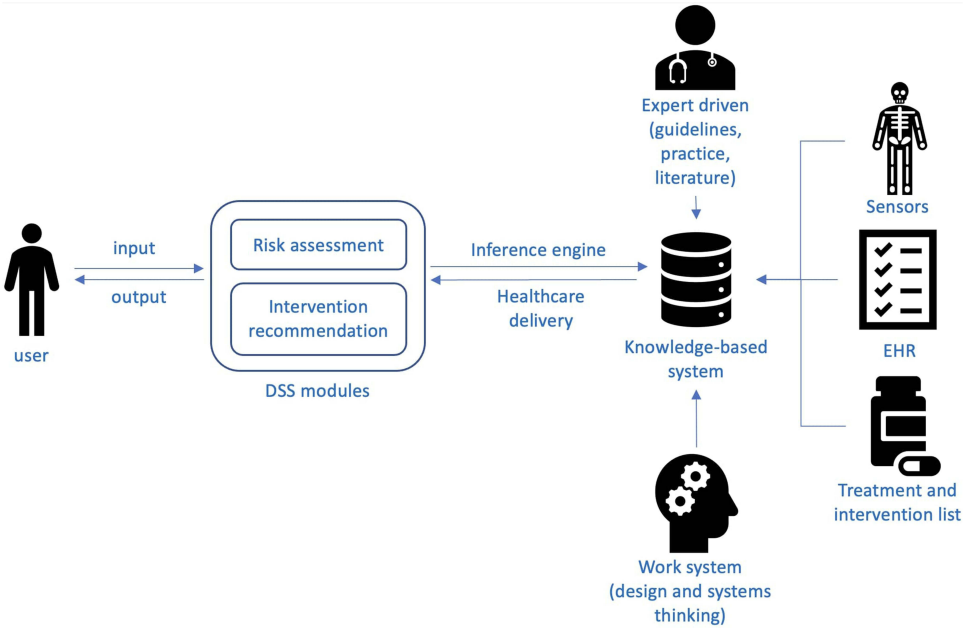

Figure 2 Framework of Decision Support Systems.

medically and practically applicable. An inference engine processes the data, applying ML models to generate tailored prevention strategies. These may include physical therapy recommendations, medication adjustments, environmental modifications, or caregiver education. Finally, the system delivers intervention recommendations through intuitive interfaces designed for clinicians, patients, and caregivers. The DSS fosters trust and encourages shared decision-making by prioritizing explainability and usability. This proactive, human-centered approach reduces fall incidents and enhances patient safety and healthcare efficiency.

Integrating fall prediction models into real-time human-centered AI DSS enables clinical teams to proactively identify patients at risk of falls and implement preventive measures. Moreover, the adoption of patient-tailored fall prevention programs involving active engagement of patients and families in the fall prevention process will improve patient outcomes by utilizing valid screening scales and evidence-based interventions through human-centered AI DSS. Human-centered design principles are pivotal in the development of DSS, ensuring that the information presented is contextually relevant and easily understandable for better adoption in practice. Furthermore, the validation of fall risk assessment tools combined with clinical judgment has been emphasized as an accurate method for predicting fall risks and enhancing patient safety.

Analysis and Discussion

Fall risk assessment is a critical component of patient care, particularly in healthcare settings where falls are common. Several tools have been developed to evaluate the likelihood of a patient experiencing a fall. These tools typically involve assessing multiple risk factors and assigning scores to determine the overall risk level. However, the effectiveness of these tools may vary, leading to ongoing research efforts to enhance their predictive accuracy.[40] Implementing risk assessments followed by targeted interventions can effectively reduce the risk of falls, as shown in Figure 3. These strategies not only enhance patient safety but also lead to cost savings by preventing fall-related injuries and deterioration. In the context of patient care, digital innovation strategies supported by engagement and empowerment have

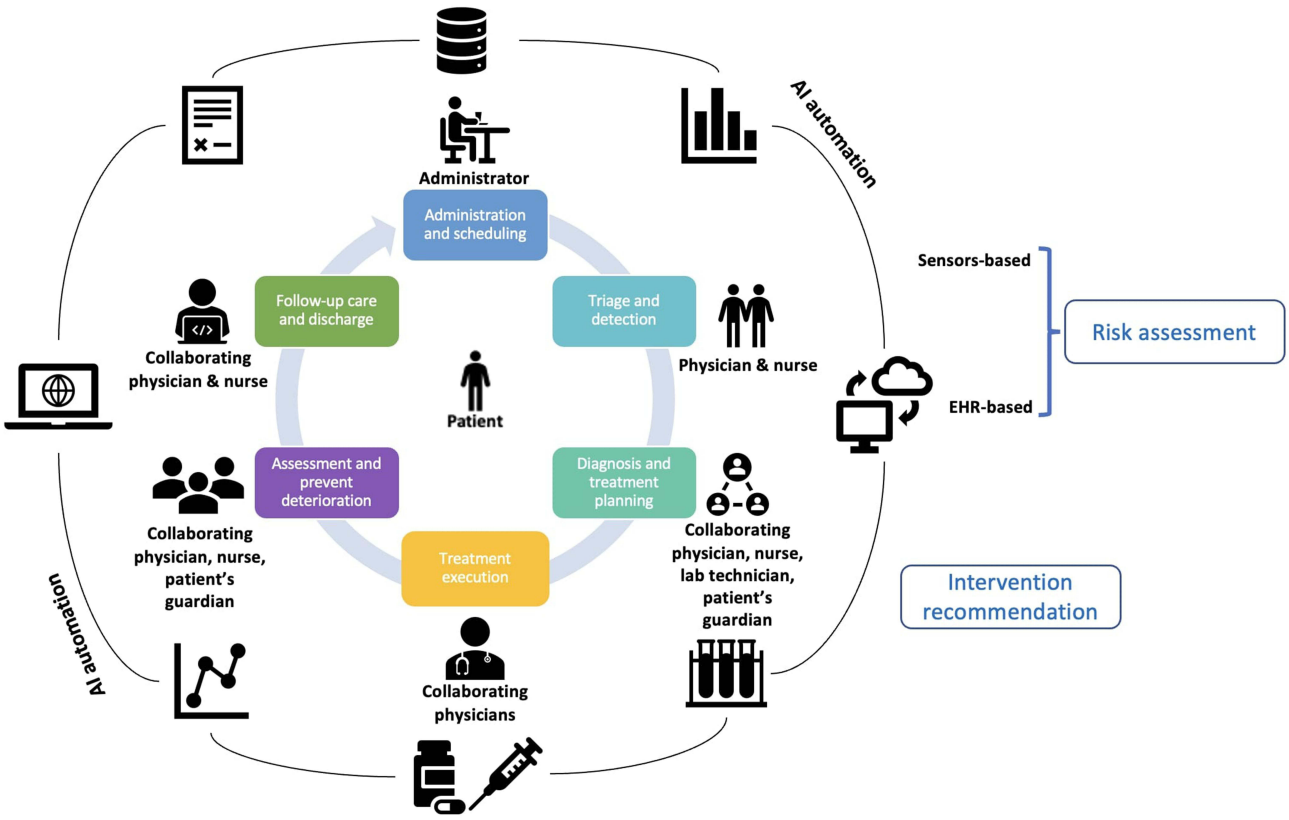

Figure 3 Improved workflow after the implementation of human-centered AI-based DSS.

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significant implications for hospital decision-making. Standard tools like the Morse Fall Scale have demonstrated inconsistent predictive accuracy across clinical settings,[41] prompting research into advanced solutions. To address this gap, digital innovation strategies like a wearable sensor system paired with an AI algorithm that analyzes gait patterns, vital signs, and EHR data.[42] A centralized digital dashboard aggregates data from EHR, bed alarms, and staff documentation to visualize fall risk trends across units.[43] Dynamic risk detection aim to move beyond once-per-shift assessments to continuous monitoring and reduces alarm fatigue by prioritizing high-probability risks.[44] Understanding patient ecosystems and social support networks can empower patients to manage their health effectively. This patient-centered approach to human-centered AI DSS can lead to more personalized and effective care delivery within hospitals.

Identifying individual risk factors that can be influenced is crucial in choosing and applying preventive interventions effectively. Interventions for fall prevention can vary, including case management at home, which involves a multidimensional assessment, an explanation of fall risk factors, and the development of an individualized intervention plan based on identified risk factors. Furthermore, interventions must address multiple components simultaneously to mitigate fall risks effectively.

Efforts to streamline human-centered AI DSS should prioritize seamless integration into clinical workflows with minimal disruptions, aligning with the preferences of healthcare providers. Implementing organization-wide training and education, utilizing standardized fall risk assessment tools, and conducting root-cause analyses after falls are essential to successful fall prevention programs. Collaborative efforts involving healthcare providers, patients, families, and healthcare systems are necessary to address the multifaceted challenges associated with patient falls. Ideally, the integration of this system will lead to an improvement in fall prediction and pre-fall interventions to prevent occurrences (Figure 4). Ideally, all patients will be assigned a fall risk score based on the available EHR data. Patient management regarding fall risk will depend on this score, as it indicates the severity of the patient's fall risk. All patients should be educated about the location of the alarm triggers in their rooms/beds, and the healthcare workers should discuss the topic of fall risk with the patient. Patients at medium (4–6) to high (7–10) risk of falling should be provided with dual motor task training and with walking aids or assisted walking. Patients at high risk of falling should be provided with timed toileting to ensure their safety, and they should also be provided with balance and mobility training when applicable. The fall risk score should be updated weekly using the data from the newly fitted wrist monitor. This way, the healthcare workers are constantly updated about changes in balance or gait, improving patient fall prevention efforts in the healthcare facility.

Integrating human-centered AI DSS in fall prevention strategies presents significant societal benefits, particularly in reducing fall incidences and mitigating long-term physical and psychological impacts on vulnerable populations, such as the elderly and those with chronic conditions. This proactive approach enhances the quality of life and promotes greater independence for these individuals and substantially decreases the incidence of fall-related injuries. Consequently, this reduction alleviates the burden on emergency services and long-term care facilities, reallocating healthcare resources to other critical areas. The application of AI in this context not only aims to lower healthcare costs but also improves patient outcomes and enhances the efficiency of healthcare systems at large. The broader impact of these advancements extends beyond the patients themselves, influencing the well-being of their families, communities, and society as a whole.

Building on these societal advantages, the adoption of the proposed human-centered AI DSS for fall prevention also heralds a pivotal technological advancement and transformative opportunity for healthcare organizations. This shift enables the transition from traditional, reactive patient care delivery models to proactive, human-centered AI care paradigms. Employing predictive analytics, advanced sensor technologies, and real-time data monitoring enhances the capability to predict and prevent potential risks before incidents occur. Moreover, this shift fosters a culture of continuous innovation and improvement within healthcare institutions. The implementation of new care protocols, driven by interdisciplinary collaboration, raises patient engagement and satisfaction through cutting-edge, AI-enhanced, data-driven decision-making processes. This new human-centered AI DSS, in turn, equips healthcare providers to stay competitive by adapting to technological advancements and improving service delivery within an evolving healthcare landscape.

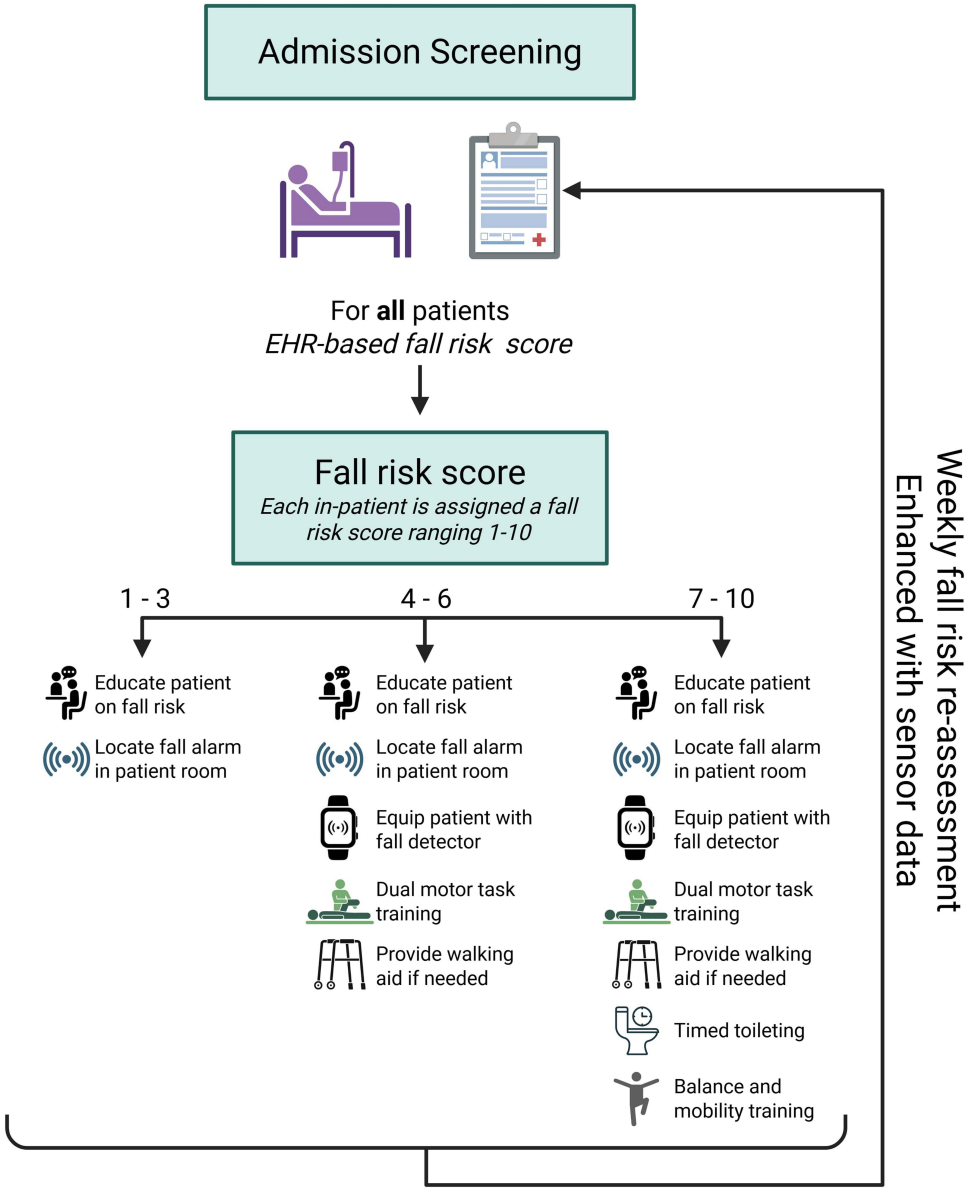

Figure 4 Ideal patient fall prediction workflow. Created in BioRender. Kannout, H. (2025) https://BioRender.com/mj8cmst.

Conclusion

This study has highlighted the transformative potential of AI in developing fall prevention strategies within healthcare settings. By integrating human and AI-driven predictive analytics into DSS, healthcare providers can shift from reactive to proactive models of patient care. This paradigm shift improves patient safety by significantly reducing the incidence of falls and enhances operational efficiencies, thereby reducing healthcare costs.

The implementation of human-centered AI DSS utilizes advanced sensors and real-time data monitoring to assess patient risk dynamically. This makes personalized interventions more effective at mitigating risk than traditional one-size -fits-all approaches. Moreover, the adoption of a systems thinking approach provides a comprehensive framework for analyzing the complex interactions within healthcare systems, enabling a holistic improvement in patient care and safety.

The benefits of human-centered AI DSS in fall risk assessment and prevention extend beyond individual patient outcomes, impacting the broader healthcare system by effective resource allocations, which can then be reallocated to other pressing healthcare needs. This human-centered AI DSS has the potential to improve the overall quality of

healthcare delivery, promoting a more sustainable healthcare environment. However, successful implementation of these systems requires overcoming barriers related to technology adoption, data integration, staff training and automation bias.[45,46] It also necessitates a cultural shift within organizations towards embracing technological innovations. Future research should address these challenges, refine AI's explainability,[47] and expand its usability and adoption to diverse healthcare settings to ensure that all patients benefit from these advancements. Leveraging AI's capabilities, healthcare organizations can better protect vulnerable populations, optimize healthcare delivery, and support an environment of continuous improvement and patient-centered care.

While this study provides valuable insights into fall risk assessment and prevention, it is important to acknowledge certain limitations. First, the perspectives of frontline healthcare workers, particularly nurses, were not incorporated due to the retrospective nature of this analysis for direct stakeholder engagement at this stage. Given nurses' critical role in fall prevention, their input would have strengthened the practical applicability of our findings. To mitigate potential biases, we rigorously reviewed existing literature on nursing-led fall prevention strategies and adjusted our discussion to ensure a balanced representation. Future research should prioritize early collaboration with clinical staff through IRB-approved protocols to better capture real-world challenges and interventions. Despite this limitation, our findings remain aligned with established evidence while highlighting opportunities for more inclusive, multidisciplinary studies in this field.

Disclosure

The authors report no conflicts of interest in this work.

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