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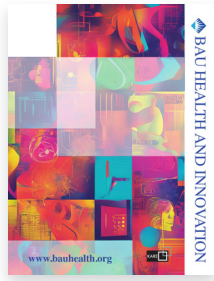


Invited Review

# Orthopedic Problems and Fall Risk in Older Adults: Innovative Preventive Approaches

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**Abstract**

Falls are a significant health issue for older adults. They can lead to injuries, disabilities, loss of independence, and higher healthcare costs. Orthopedic issues such as osteoarthritis, osteoporosis, fractures, joint replacements, spinal deformities, and foot disorders significantly increase the risk of falling. These conditions can cause pain, limit mobility, reduce proprioception, and affect balance. This creates a cycle of immobility and repeated falls, which shows the need for effective prevention methods. Traditional approaches, including exercise programs, medication, nutritional support, environmental changes, and assistive devices, continue to be vital in preventing falls. However, new technology offers fresh ways to address the complex problem of falls in older adults. Wearable sensors with inertial measurement units can continuously track walking and balance. This allows for early detection of risks and timely preventive actions. Robotics and exoskeletons provide targeted training and support, especially after orthopedic surgeries. Virtual and augmented reality tools create engaging balance training that boosts motivation and lowers the fear of falling. Tele-rehabilitation and mobile health applications offer personalized care at home, while artificial intelligence and predictive analytics provide tailored risk assessments and proactive solutions. Smart home and assisted living technologies also help by reducing hazards and providing immediate fall alerts. Fall prevention can evolve from clinic-based methods to continuous, personalized, and technology-driven strategies. These combined approaches show great potential for lowering fall-related issues, supporting independence, and improving the quality of life for the growing elderly population.

**Keywords:** Accidental falls, orthopedic procedures, telemedicine, wearable electronic devices.

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The global population is aging quickly, creating challenges for healthcare systems worldwide.[1] Falls are one of the most serious health issues for older adults. They are a major cause of injuries, disabilities, loss of independence, and even death.[2] Studies show that about one in three people over 65 experiences at least one fall each year. A significant number of these falls result in hospitalization or a need for long-term care.[2,3] Beyond individual impacts, falls create substantial economic and social burdens for families and healthcare systems.[4] In the United States, healthcare costs linked to non-fatal falls among older adults reached around $80 billion in 2020. Between 2016 and 2018, there were nearly 922,000 hospital stays and 2.3 million emergency department visits due to falls.[4] In addition, falls lead to indirect societal burdens such as long-term care needs, strain on informal caregivers, loss of independence, and a decreased quality of life.[3,5] Beyond musculoskeletal conditions, other

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well-established risk factors such as multimorbidity and adverse drug interactions are also highly prevalent among older adults and further increase their vulnerability.[6] It is important to acknowledge that multimorbidity and drug interactions may also play a role in increasing fall risk and can indirectly worsen orthopedic outcomes in older adults. Orthopedic conditions significantly contribute to the risk of falls in older adults. Severe knee osteoarthritis can almost double the chance of falling due to pain, stiffness, limited mobility, and reduced proprioception.[7,8] Osteoporotic fractures, especially in the hip and spine, worsen disability and contribute to cycles of immobility and repeated falls.[9] Moreover, balance and walking problems following orthopedic surgery can extend rehabilitation and increase the risk of falls, highlighting the importance of orthopedic health in fall prevention.[10]

Given the multiple factors involved in falls, prevention strategies need to go beyond treating single issues. Evidence supports using comprehensive approaches, including exercise programs to improve strength and balance, medication and nutrition for osteoporosis, environmental adjustments, and assistive devices to reduce fall risk.[10,11] Recently, innovative methods such as wearable sensors, tele-rehabilitation, and robotic therapies have gained attention for their potential to enhance fall prevention for older adults with orthopedic disorders.[12] However, practical barriers such as high initial costs, limited accessibility in rural or resource-constrained areas, and usability challenges for older adults may limit the widespread adoption of these technologies in clinical practice.[13] In particular, low digital literacy has been identified as a major barrier, since many older adults face difficulties in operating digital devices, navigating applications, and maintaining confidence in technology use without additional support.[13] Physical limitations, lack of technical support, and affordability issues further restrict technology adoption in aging populations.[14] In addition, inequities in infrastructure and access have been reported as significant challenges in implementing telehealth and tele-rehabilitation services.[15] Addressing these issues is essential to ensure that innovative solutions can be effectively implemented alongside traditional strategies.

This review aims to summarize the current evidence on the link between orthopedic problems and fall risk in older adults while highlighting both traditional and innovative prevention strategies that can help reduce falls in this growing population. To ensure a broad and balanced overview, we searched PubMed, Scopus, and Web of Science for studies published in English up to 2025, using combinations of terms such as "falls," "older adults," "orthopedic problems," "wearable technologies," "tele-rehabilitation," "virtual reality," "exoskeletons," and "artificial intelligence." Additional relevant studies were identified by screening the reference lists of key articles.

## Orthopedic Problems and Their Contribution to Fall Risk

Orthopedic issues are among the key contributors to falls in older adults. Osteoarthritis in the hip and knee can limit joint movement, change how a person walks, and increase instability due to pain, stiffness, and impaired proprioception.[7] Osteoporosis and fragility fractures, particularly in the hip and spine, worsen immobility and create a cycle of disability and repeated falls.[9] Surgical procedures such as total hip and knee replacements can restore function but may lead to muscle weakness, balance issues, and walking difficulties that keep the risk of falling high during recovery.[10] Similarly, spinal deformities such as kyphosis and scoliosis can affect posture and stability, while foot and ankle issues like hallux valgus or flatfoot can disrupt weight distribution and impair balance when walking.[16,17]

The reasons behind these associations are varied. Pain, stiffness, and restricted movement reduce mobility and independence, while issues with body awareness affect muscle control. In addition, loss of muscle mass or weakness can further reduce stability when moving. Changes in posture due to altered body mechanics and compensatory movements increase the likelihood of falling across different orthopedic conditions.[18] Together, these challenges show how crucial orthopedic health is in determining fall risk among older adults.

## Innovative Preventive Strategies

### Wearable Technologies and Sensor-Based Monitoring

Wearable technologies and sensor-based monitoring systems have become valuable tools for assessing and reducing fall risk in older adults. Devices equipped with inertial measurement units (IMUs), including accelerometers, gyroscopes, and magnetometers, can objectively quantify static and dynamic balance, gait speed, step length, and postural sway. Studies have demonstrated that smartphone-embedded IMUs and wearable sensors show moderate to strong correlate with gold standard laboratory systems, such as force plates and motion capture, in evaluating balance and mobility.[12]

In addition to smartphones, wearable sensors placed on the lower back, sternum, or within smart insoles have proven reliable for continuously monitoring walking and balance in everyday environments. These sensor-based systems are capable of capturing subtle spatiotemporal gait parameters such as stride variability, postural sway, and asymmetries that are often undetectable through conventional clinical assessments.[19,20] By detecting early deviations in mobility patterns, these technologies facilitate timely identification of older adults at increased risk of falls, allowing for preventive interventions before serious injuries occur.[21] Recent prospective study has further demonstrated the utility of wearable sensors in fall-risk prediction. Howcroft et al.[22] developed fall-risk classification models based on accelerometer and pressure insole data collected during single- and dual-task walking in 75 older adults and showed that multi-sensor neural network models could achieve moderate accuracy (57%) and specificity (65%) for predicting prospective falls. These findings highlight the feasibility of using wearable sensors for point-of-care fall-risk assessment in real-world clinical settings.

In addition to risk assessment, smart insoles and inertial sensors have been adapted for fall detection and alarm systems that can differentiate between actual falls and normal activities. They can send real-time alerts to caregivers or healthcare providers.[23] This integration of monitoring, prediction, and emergency response represents a significant shift in how to support the safety and independence of older adults living in the community. Overall, these advancements show how wearable sensors improve clinical evaluations and everyday fall prevention efforts for older populations.[12]

Importantly, sensor-based monitoring allows for longitudinal tracking of mobility, enabling clinicians to identify trends over time and tailor interventions accordingly. By changing fall risk assessment from clinic-based evaluations to continuous monitoring in real life, wearable technologies promise proactive and tailored fall prevention approaches. However, barriers such as device cost, the need for technical support, and limited digital literacy among older adults may restrict widespread use of wearable monitoring in daily practice.[14]

## Robotics and Exoskeletons

Robotics and exoskeletons have become important tools for preventing falls in older adults, especially in relation to orthopedic disorders and age-related decline in function. Unlike typical physiotherapy, robotic-assisted gait training offers repetitive, specific movements that help with learning motor skills, strengthen the muscles in the lower limbs, and improve postural control.[24,25] Recent systematic reviews and clinical trials show that robotic rehabilitation can significantly improve walking speed, step length, gait symmetry, and balance in older people.[24,26] In particular, robotic exoskeletons have shown potential in speeding up recovery after hip and knee surgeries, where the risk of falling is high due to postoperative pain, limited mobility, and impaired proprioception.[27] Meta-analyses further support the use of wearable robotic devices such as hip-assist exoskeletons and motorized gait trainers in reducing energy expenditure during ambulation and enhancing long-term walking efficiency.[27,28] Overall, these findings suggest that robotics and exoskeletons are not only effective rehabilitation tools but also strategies to prevent falls, allowing older adults to maintain their independence and mobility while reducing orthopedic complications.

Exoskeletons and robotic orthoses provide external support that helps frail or sarcopenic individuals safely perform walking and balance exercises that might otherwise lead to falls.[24,29] These devices can help reduce compensatory movement patterns and support weight-bearing during ambulation, promoting safer and more efficient gait mechanics.[28] They have also proven especially useful for encouraging early mobilization after orthopedic surgeries like hip or knee arthroplasty, when the risk of falling is still elevated during recovery.[26,27] Importantly, robotic systems not only offer mechanical assistance but also provide objective feedback and real-time monitoring of gait parameters, allowing clinicians to use performance data in personalized rehabilitation plans.[30]

While cost and accessibility remain major challenges, progress in lightweight materials, portable exoskeletons, and at-home robotic training systems is making wider clinical use more feasible.[31,32] By enabling safe, intensive, and tailored rehabilitation, robotics and exoskeletons hold great promise for preventing falls and restoring mobility in older adults. Despite these benefits, the high initial costs of robotic systems and the complexity of their operation remain major barriers to adoption, particularly in resource-constrained settings.[15]

## Virtual Reality (VR) and Augmented Reality (AR)

VR and AR technologies are increasingly being explored as innovative approaches to improve balance and reduce fall risk in older adults. Recent meta-analyses show that VR-based interventions can significantly enhance balance, walking performance, and mobility, even for community-dwelling older adults without neurological disorders.[33]

VR provides immersive and interactive environments that let individuals practice challenging balance and gait tasks safely, while also addressing fears of falling and improving reaction times.[34] AR interventions are gaining popularity as well; systematic reviews indicate that AR balance training effectively boosts mobility, postural stability, and reduces fall risk, providing a more engaging and accessible alternative to regular exercise programs.[35] By stimulating multisensory feedback and promoting motor learning through repetitive, game-like tasks, VR and AR enhance not just balance but also confidence and long-term independence in older adults.[36] Randomized controlled trials have shown that VR-based training improves balance and mobility in older adults at risk of falls, with significant gains in Berg Balance Scale and Timed Up and Go scores.[33] In individuals with knee osteoarthritis, VR exercise programs have been found to reduce pain and improve Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) total and pain scores. They also enhance quadriceps and hamstring strength and support postural stability, although effects on stiffness and overall physical function remain inconsistent.[37]

The interactive and gamified features of VR and AR platforms boost patient engagement and adherence to rehabilitation programs, often exceeding traditional exercise methods in motivation and enjoyment.[38] Recent reviews highlight that gamification elements like performance feedback and rewards enhance motivation and compliance among older adults involved in fall-prevention programs.[39] Although there are still challenges around access, equipment costs, and the need for tailored program designs, VR and AR in fall-prevention strategies show great promise for improving functional outcomes and quality of life in older adults.[40] By combining engagement with clinical effectiveness, these technologies are paving the way for the integration of gamified interventions into mainstream fall-prevention strategies. Although challenges remain regarding accessibility, equipment costs, and the need for tailored program design, the integration of VR and AR into fall-prevention strategies represents a promising frontier for enhancing functional outcomes and quality of life in older adults.[41] These practical limitations, including usability issues and adaptation challenges in older adults, have been noted as important barriers to their widespread integration into rehabilitation programs.[42]

## Tele-Rehabilitation and Mobile Health (mHealth) Applications

Tele-rehabilitation and mHealth applications have emerged as affordable and accessible options to support fall prevention in older adults.[43] Through video conferencing, smartphone apps, and remote monitoring systems, older individuals can engage in supervised exercise programs and get personalized feedback without frequent clinical visits.[44] This method is especially helpful for those with orthopedic conditions or limited mobility, as traveling to rehabilitation centers can be difficult or unsafe.[45]

mHealth platforms can record physical activity, gait data, and balance performance with built-in sensors while offering reminders, educational information, and progress monitoring.[46] Studies suggest that tele-rehabilitation methods, like remote-guided balance and strength training, work as effectively as traditional in-person therapy for improving functional outcomes and reducing fall risk.[44] In addition, mobile applications often use gamification and interactive features, which may increase patient engagement and adherence to prescribed exercises.[38]

By bridging the gap between clinical care and home practice, tele-rehabilitation and mHealth tools enable ongoing, personalized fall prevention strategies. Their scalability and ability to work with wearable or smart home technologies offer the potential for comprehensive and sustainable rehabilitation models for older adults at risk of falling.[43]

Evidence from clinical trials highlights the effectiveness of tele-rehabilitation in orthopedic populations. In a randomized controlled trial of patients with knee osteoarthritis, a 4-week program of remote physiotherapy sessions delivered 3 times/week produced outcomes comparable to conventional outpatient therapy, with significant reductions in pain, improvements in WOMAC scores, and better quality of life in several SF-36 domains (physical functioning, role limitation, energy, and pain) at 3-month follow-up.[47] These findings suggest that tele-rehabilitation can be safely and effectively incorporated alongside traditional therapy in managing knee osteoarthritis. Furthermore, a systematic review and meta-analysis including six randomized controlled trials (n=734) found that telerehabilitation strategies were more effective than usual care in reducing pain, although improvements in physical function were not statistically significant.[48] Collectively, these results indicate that while tele-rehabilitation consistently alleviates pain in knee osteoarthritis, its effects on physical function may vary depending on program design, duration, and patient characteristics. Although tele-rehabilitation increases accessibility, digital inequities, limited internet infrastructure, and ethical concerns about equitable access remain significant challenges for older adults.[15]

**Table 1.** Summary of innovative technologies for fall prevention in older adults

| Technology | Reported benefits | Key limitations |
|---|---|---|
| Wearable sensors | Early fall risk detection, continuous monitoring, real-time alerts, objective gait/balance data[19–23] | Device cost, need for technical support, and limited digital literacy[14] |
| Robotics and exoskeletons | Improves gait speed, symmetry, postural control; supports early mobilization[24–28] | High cost, limited accessibility, complexity of use[15] |
| Virtual and augmented reality | Enhances balance, reduces fear of falling, and gamified training increases adherence[33–37] | Equipment cost, usability/adaptation issues in older adults[40–42] |
| Tele-rehabilitation and mHealth | Provides remote access, personalized feedback without clinical visits, improves pain and quality of life[43–48] | Internet access required, digital inequities, variable effects on function[15] |
| Artificial intelligence and predictive analytics | Personalized risk profiling, early identification of high-risk patients, tailored interventions[49–51] | Data privacy, integration challenges in clinical workflow[52] |
| Smart home and ambient assisted living systems | Fall detection and alerting reduce environmental hazards, support independence at home[53–56] | Cost, digital literacy, privacy concerns[56] |

## Artificial Intelligence (AI) and Predictive Analytics

AI and predictive analytics are increasingly being used in fall prevention, allowing for highly personalized and proactive care for older adults with orthopedic conditions. By examining large datasets from wearable sensors, gait assessments, electronic health records, and imaging studies, AI algorithms can identify subtle patterns that may precede falls and create individual risk profiles.[49] This helps clinicians detect high-risk patients sooner and apply targeted interventions to prevent falls. Machine learning models have shown good accuracy in predicting falls by combining factors like variability in gait, balance metrics, medication use, and other health issues.[50] For orthopedic patients, such as those with osteoarthritis or recovering from joint replacement surgery, AI systems can adjust predictions based on any changes in mobility or rehabilitation progress.[51] Predictive models also allow for remote monitoring and support, aiding healthcare providers in optimizing exercise plans, modifying medications, and efficiently allocating rehabilitation resources.[51]

Despite challenges around data privacy, algorithm transparency, and fitting into clinical workflows, AI-driven predictive analytics offer a groundbreaking way to prevent falls. By shifting focus from reactive to preventive care, these technologies have the potential to enhance safety, independence, and quality of life for older adults at risk of falling.[52]

## Smart Home and Ambient Assisted Living (AAL) Technologies

Smart home systems and AAL technologies are becoming essential tools for preventing falls and improving safety for older adults. These systems use motion sensors, pressure mats, and video monitoring to identify unusual movement patterns or potential falls in the home. They automatically alert caregivers or healthcare providers to ensure timely help and minimize complications from delayed medical care.[53,54] In addition, smart home technologies help prevent falls by tackling environmental risks. Features such as automated lighting, obstacle detection, and voice-controlled assistants reduce common hazards such as poor visibility and cluttered pathways.[55] Integration with wearable devices and tele-rehabilitation platforms allows for ongoing monitoring of mobility and physical activity, offering a complete approach to fall prevention.

Importantly, AAL technologies focus on independence and quality of life. They enable older adults to stay safely in their homes while lowering the need for institutional care and easing the burden on caregivers.[31] However, barriers such as cost, digital literacy, and privacy concerns can slow down adoption. Advances in user-friendly design and affordability are making smart home solutions more available and acceptable to older populations.[56] A summary of the innovative technologies, their reported benefits, and limitations is provided in Table 1.

### Limitations

This narrative review is not a systematic analysis, so some relevant studies may have been left out. Furthermore, much of the evidence on new technologies is still developing, with differences in study designs, populations, and outcomes. These factors may limit how broadly the findings can be applied, highlighting the need for more high-quality research.

## Conclusion

Falls remain to be a major health issue for older adults. Orthopedic conditions such as osteoarthritis, osteoporosis, fractures, joint replacements, spinal deformities, and

foot disorders significantly increase vulnerability. These disorders result in pain, limited mobility, balance issues, and postural instability, creating a cycle of immobility and repeated falls. Traditional prevention strategies, such as exercise programs, medication management, and environmental changes, are still important but may not fully address the complexities of fall risk in this group.

Recent technological advancements, including wearable sensors, robotics, virtual and AR, tele-rehabilitation, AI, and smart home systems, show great potential for preventing falls among older adults. These tools allow for continuous monitoring, customized rehabilitation, engaging training, and safer home settings. By moving beyond traditional clinic-based methods, they provide new opportunities to promote independence, reduce injuries, and enhance quality of life for older populations.

## Future Perspectives

The future of fall prevention for older adults relies on integrating innovative tools such as wearable sensors, AI, robotics, VR/AR, and smart home systems to provide ongoing monitoring and personalized care. Challenges such as cost, digital literacy, and privacy still need to be addressed. However, with user-focused design and robust clinical evidence, technology-driven, multidisciplinary approaches have great potential to lower fall risk and boost quality of life for aging populations.

In addition to the growing evidence of effectiveness, pilot applications and preliminary experiences suggest potential pathways for integrating these technologies into practice. For example, community-based VR programs may offer a feasible and engaging approach for older adults, while tele-rehabilitation models could provide accessible home-based care for conditions. Similarly, exoskeleton-assisted recovery after joint replacement has been explored as a way to support early mobilization. These emerging applications remain preliminary but point to possible directions for wider adoption, even in resource-constrained healthcare settings.

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