smooth lower-limb motion. The fusion of dry bio signals, Kalman-LSTM control, and back-drivable actuation achieved high accuracy and minimal delay on compact hardware. These results highlight a viable path toward affordable assistive exoskeletons suitable for rehabilitation and daily-living mobility support. Continued research will focus on real-world gait trials and energy optimization.

Acknowledgements. The authors thank the Mechatronics Laboratory, Chinhoyi University of Technology, for technical support and facilities.

References

1. Adaptive impedance control for wearable exoskeleton robots / S. Bai, W. Song, H. Ma, X. Liu // Sensors. – 2021. – Vol. 21, № 5. – Art. 1579.
2. Powered exoskeletons for bipedal locomotion after spinal cord injury / J. L. Contreras-Vidal [et al.] // Journal of Neural Engineering. – 2016. – № 3. – Art. 031001.
3. Dollar, A. M. Lower-extremity exoskeletons and active orthoses / A. M. Dollar, H. Herr // IEEE Transactions on Robotics. – 2008. – Vol. 24, № 1. – P. 144–158.
4. Neuralink and the brain–machine interface / E. Musk [et al.] // Nature Neuroscience. – 2020. – Vol. 23, № 2. – P. 245–256.
5. Williams, R. Integration of AI in exoskeleton control systems / R. Williams, L. Brown // IEEE Transactions on Neural Systems and Rehabilitation Engineering. – 2022. – Vol. 30, № 5. – P. 789–799.
6. World Health Organization. World Report on Disability / WHO. – Geneva: World Health Organization, 2011. – 350 p.

UDC 681

HEALTHCARE 4.0 TECHNOLOGIES FOR PATIENT TRANSFER IN OPERATING THEATRES: A SYSTEMATIC REVIEW

Winnie Mutenhabundo, Kudzanayi Chiteka, Rindai Mahoso, Munyaradzi Mupona

Harare Institute of Technology, Harare, Zimbabwey

Abstract. Safe patient transfer in operating theatres is vital yet often neglected, exposing healthcare workers to musculoskeletal injuries and patients to avoidable risks. Healthcare 4.0 combining Artificial Intelligence (AI), Internet of Medical Things (IoMT), robotics, and cloud computing offers solutions for safer and more efficient workflows. This systematic review of 32 studies (2019–2023) found that AI predicts complications, robotics reduce caregiver strain by up to 40 %, IoMT supports continuous monitoring, and cloud platforms streamline operations. However, in low- and middle-income countries such as Zimbabwe, adoption is hindered by cost, infrastructure, and skills gaps, requiring phased, low-cost digital integration.

Keywords: Healthcare, Health 4.0, patient transfer, AI, robotics.

Address for correspondence: Winnie Mutenhabundo, 277 Ganges Road, Belvedere, Harare, Zimbabwe
e-mail: wmutenhabundo@hit.ac.zw

Introduction. Patient transfer in operating theatres is a critical element of perioperative safety, yet it continues to rely heavily on manual handling methods. The World Health Organization (2021) reports that nearly 40 % of nurses experience chronic back pain from patient transfer activities, contributing to absenteeism and reduced productivity. Traditional aids like slide sheets and hoists partially mitigate physical strain but fail to enhance workflow efficiency or address real-time risk factors. Healthcare 4.0 technologies–AI, IoMT, robotics, and cloud computing–are increasingly deployed to bridge these gaps by enabling data-driven, automated, and adaptive patient transfer systems. In high-income settings, robotic-assisted transfer systems have reduced nurse strain by up to 40 % (Kim et al., 2024), but LMICs such as Zimbabwe face infrastructural and financial limitations.

Background and Conceptual Framework. Healthcare 4.0 represents the evolution from earlier healthcare generations: digitisation (Healthcare 2.0) and telemedicine (Healthcare 3.0) to fully integrated, data-intelligent systems (Healthcare 4.0). Drawing from Industry 4.0, it incorporates cyber-physical systems, IoMT, AI, and cloud computing for seamless connectivity, automation, and analytics (Li et al., 2017; Mwanza et al., 2023). AI enhances predictive monitoring, detecting early signs of patient distress or mechanical malfunction, while robotics reduce the need for physical lifting (Lin et al., 2021). IoMT networks integrate wearables and smart sensors to collect continuous data, enabling cloud-based decision support (Taylor et al., 2023). Together, these innovations promote precision, safety, and efficiency in perioperative workflows.

However, in LMICs, widespread deployment faces systemic barriers–limited broadband connectivity, unstable power supply, and cost constraints (Muchiri, 2022). Context-appropriate approaches, such as low-cost IoMT devices and semi-automated transfer mechanisms fabricated from locally available materials, have shown promise (Richarz et al., 2023). These frugal innovations emphasize adaptability, affordability, and scalability as foundational principles for healthcare digital transformation in developing contexts.

Methodology. This review followed PRISMA guidelines (Moher et al., 2010). Databases searched included Scopus, PubMed, Web of Science, IEEE Xplore, and ScienceDirect for the years 2019–2023. Keywords included "Healthcare 4.0", "patient transfer", "AI", "robotics", "IoMT", and "cloud computing." A total of 243 records were retrieved, 48 duplicates removed, and 195 screened. Following full-text review, 32 studies met inclusion criteria: peerreviewed, English, and focused on perioperative patient transfer using Healthcare 4.0 technologies. Data were categorized thematically into benefits, challenges, and contextual implications for LMICs.

Discussion. The synthesis demonstrates that Healthcare 4.0 technologies transform perioperative workflows through automation and predictive intelligence. AI-based models analyse physiological data to forecast transfer complications, while robotic systems automate high-risk lifting and movement tasks, reducing strain-related injuries. IoMT platforms interconnect monitoring systems to cloud analytics, allowing proactive safety alerts and workflow optimization. These integrated systems have improved nurse well-being, reduced operational errors, and increased patient safety in technologically advanced hospitals (Kim et al., 2024).

Nevertheless, high equipment costs, weak digital infrastructure, and limited workforce digital literacy impede implementation in LMICs. Ethical and regulatory issues–especially data privacy, algorithmic bias, and accountability for AI-driven errors–remain unresolved (Moghaddasi et al., 2021). Furthermore, many healthcare workers in resource-constrained settings express resistance to automation, fearing job displacement and reduced human interaction with patients.

To overcome these barriers, phased and locally driven adoption strategies are vital. Early-stage integration of IoMT and AI tools using mobile platforms can deliver immediate safety gains without major capital investment, (Al-Assaf et al., 2024). Medium-term strategies can introduce semi-automated systems in tertiary hospitals, supported by national digital health frameworks. In the long term, fully networked AI–robotic systems could synchronize with cloud-based national health databases, enhancing resource planning, predictive maintenance, and clinical coordination.

For Zimbabwe, a phased roadmap is proposed: (i) short term (1–2 years) – deploy IoMT sensors and AI monitoring in district hospitals; (ii) medium term (3–5 years) – introduce robotic aids in tertiary hospitals such as Parirenyatwa and Mpilo Central; and (iii) long term (5–10 years) – integrate cloud-linked AI–robotic systems nationwide. This strategy balances feasibility, scalability, and alignment with existing e-health initiatives.

Conclusion and Recommendations. Healthcare 4.0 offers a viable pathway to safer and more efficient patient transfer practices. While developed countries have achieved measurable gains, LMICs require strategic, cost-sensitive adoption models. Zimbabwe and similar nations should prioritize digital infrastructure, training, and policy frameworks to enable gradual integration of AI, IoMT, and robotics. A strong public–private partnership model can support funding and local innovation, ensuring sustainability. Future studies should investigate ethical frameworks, cost-effectiveness analyses, and pilot-scale implementation to guide large-scale Healthcare 4.0 transformation in African hospitals.

Acknowledgments. The authors express their sincere gratitude to the Harare Institute of Technology, Department of Industrial and Manufacturing Engineering, for providing technical support and access to research facilities. Special thanks are extended to colleagues and reviewers whose constructive feedback helped refine this study. The authors also acknowledge the valuable contributions of all healthcare professionals who shared insights that informed the contextual analysis of Healthcare 4.0 technologies in Zimbabwe.

References

1. Industrial wireless networks in the context of Industry 4.0 / X. Li, W. Zhang, H. Wang [et al.] // Wireless Networks. – 2017. – Vol. 23, № 1. – P. 23–41.
2. Moher, D. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement / D. Moher [et al.] // International Journal of Surgery. – 2010. – Vol. 8, № 5. – P. 336–341.
3. Mwanza, J. Impact of Industry 4.0 on healthcare systems of LMICs: A systematic review / J. Mwanza, A. Telukdarie, T. Igusa // Health and Technology. – 2023. – Vol. 13, № 1. – P. 35–52.
4. Usability of smart transfer-assistive robots for care workers / Y. S. Kim [et al.] // Disability and Rehabilitation: Assistive Technology. – 2024. – № 8. – P. 1864–1870.
5. Impact of mechanical devices on musculoskeletal injuries in healthcare personnel / H. Richarz [et al.] // Journal of Occupational Health. – 2023. – № 1. – Art. e12423.
6. Wearable Vital Signs Monitoring for Patients With Asthma: A Review / L. Taylor [et al.] // IEEE Sensors Journal. – 2023. – Vol. 23, № 3. – P. 1734–1751.
7. World Health Organization. Occupational safety and patient transfer risks in healthcare / WHO. – Geneva: World Health Organization, 2021. – 89 p.

UDC 681

THE IMPERATIVE OF QUALITY ASSURANCE: ENHANCING ENGAGEMENT AND RETENTION OF GENERATION Z IN ONLINE ENGINEERING EDUCATION

Musiiwa F., Nyaude P.

Harare Institute of Technology, Harare, Zimbabwe

Abstract This paper examines how Quality Assurance (QA) frameworks can be adapted to boost engagement and retention among Generation Z learners in online Electronic Engineering courses. It emphasizes the unique expectations of Gen Z interactivity, relevance, and technological integration and critiques traditional online delivery methods. The study introduces a three-pillar, Gen Z-focused QA framework: Agile and Authentic Pedagogy, a Technologically Rich Ecosystem, and Holistic Student Support Systems. By aligning instructional design, technology, and student support, this model enhances motivation, learning effectiveness, and persistence in challenging engineering programs.