Technological innovation and management in rehabilitation nursing: Challenges and solutions in the Portuguese context

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Abstract

This article investigates the challenges and opportunities associated with the integration of technological innovations in rehabilitation nursing, with a particular focus on the Portuguese context and its international connections. Drawing on a narrative literature review, complemented by the analysis of two practical case studies, it identifies cultural, financial, and organisational barriers, as well as the transformative potential of solutions such as artificial intelligence, telemedicine, and assistive devices. Despite the clear benefits of these technologies in personalising care and optimising resources, their implementation remains constrained by infrastructural limitations, institutional resistance, and gaps in professional training. International reference experiences—such as those of the Mayo Clinic, the Cleveland Clinic, and the Spanish KiReS system—is compared with national initiatives coordinated by the Escola Superior de Enfermagem de Coimbra (ESEnfC), through TecCare, the Health Sciences Research Unit: Nursing (UICISA: E), and with the support of the Agência Nacional de Inovação (ANI). Projects such as the Subcutaneous Hydration Device (DHS), DigiNurse, and smart clothing for the prevention of pressure ulcers demonstrate how academic entrepreneurship can drive innovative clinical solutions that are scientifically validated and tailored to the real needs of the healthcare system. The original contribution of this study lies in the critical articulation between international and national experiences and in the interface between strategic management, technological innovation, and the humanisation of care. It concludes that this integrated model represents a promising pathway to generate measurable improvements in clinical outcomes and to support sustainable advances in the healthcare sector.

Keywords: Health Entrepreneurship; Healthcare Management; Personalised Care; Rehabilitation Nursing; Technological Innovation.

1. Introduction

Innovation is the driving force that propels healthcare into the future. Addressing today's challenges with tomorrow's solutions is the essence of progress (Leite, 2024). In rehabilitation nursing, this perspective is particularly relevant, as this field is crucial for the recovery of patients with chronic conditions or following traumatic events. The incorporation of innovations into management and clinical practice, therefore, becomes a decisive factor for improving care and clinical outcomes (Lau, 2021).

However, one of the greatest challenges that persists in the healthcare sector is the effective integration between technological advances and the personalisation of care. Despite progress achieved, a significant gap remains between technical innovation and its practical translation, particularly in meeting patients' specific needs. Recent studies highlight the transformative potential of emerging technologies. Guarducci et al. (2025), for instance, investigate the applicability of wearable sensors for remote monitoring, underscoring their usefulness in optimising care. Similarly, Christensen, Grossman and Hwang (2009) argue that disruptive technological solutions can reshape healthcare services, increasing accessibility and efficiency, especially in resource-limited settings.

It is important to recognise, however, that healthcare innovation is not merely a technical process, but also an organisational, strategic, and pedagogical phenomenon, with implications for professional culture and the training of future nurses. In this context, the role of academic entrepreneurship as a catalyst for innovation is of

relevance. A concrete example is the Escola Superior de Enfermagem de Coimbra (ESEnfC), which, in collaboration with the Health Sciences Research Unit: Nursing (UICISA: E) and with the support of the Agência Nacional de Inovação (ANI), has developed high-impact projects such as DigiNurse — which validates digital competencies in nursing students (Parreira, Santos-Costa & Graveto, 2021) — smart textiles for the prevention of pressure ulcers (Salgueiro-Oliveira, Parreira & Martins, 2023), and studies on digital literacy in nursing (Gonçalves, Parreira & Salgueiro-Oliveira, 2022).

This article, therefore, aims to understand how the integration of emerging technologies—such as artificial intelligence, telemedicine, wearable devices, and assistive solutions—can transform the practice of rehabilitation nursing. The objective is to identify cultural, organisational, and financial barriers that hinder the adoption of innovations; to analyse how strategic management and academic entrepreneurship can facilitate this integration, and to propose strategies that ensure an ethical, humanised, and sustainable implementation.

By articulating international literature with validated local experiences, this study offers a critical reflection on the challenges and opportunities of technological innovation in rehabilitation nursing, contributing evidence and practical proposals for managers, healthcare professionals, and policymakers committed to the modernisation of care.

2. Management in Rehabilitation Nursing

Management is a central element for the success of rehabilitation nursing, being essential for the efficient coordination of care and the optimisation of resources, with direct impacts on clinical outcomes and patient satisfaction (Porter & Teisberg, 2006). Classical models, such as competency-based management and outcomes-based management, play a key role in defining responsibilities and measuring performance against concrete metrics (Donabedian, 1988; Greenhalgh et al., 2018). Furthermore, established practices such as the use of information systems and continuous professional training have proven effective in improving care (Kitson et al., 2013).

However, the healthcare sector faces significant challenges in adapting traditional models to a constantly evolving digital environment. The integration of innovative technologies, such as telemedicine and assistive devices, not only transforms care but also requires new forms of organisation and management (Wang et al., 2024). In the context of rehabilitation nursing, entrepreneurial strategies are increasingly relevant, enabling the efficient allocation of resources and a more effective response to patients' needs (Wong, Leung & Wang, 2020)

Authors such as Kwak and Lee (2022) emphasise that overcoming cultural and organisational resistance is essential for the full adoption of technological innovations. This transformation demands resilient managers capable of fostering an organisational culture open to change and of leading their teams with confidence and clarity in times of uncertainty.

The adoption of innovative technologies in rehabilitation nursing faces multiple obstacles, ranging from cultural dimensions to organisational barriers. As highlighted by Herzlinger (2006), Greenhalgh et al. (2017), Kim and Lee (2022), Johnson and Martinez (2024), and Nguyen (2024), such barriers can compromise the effectiveness of implementation but may also be overcome through appropriate management strategies. Table 1 summarises these barriers and provides practical examples in the healthcare sector, as well as the main approaches to addressing them.

The study by Kim and Lee (2022) highlights several cultural and organisational barriers to the adoption of technological innovations, identifying ways to overcome them:

Table 1: Barriers and strategies for the implementation of technologies: a focus on the healthcare sector

Category	Description	Example in the healthcare sector
Cultural barriers		
Fear of the unknown	Staff fear losing control or being replaced by technologies.	Fear of AI and wearable devices replacing professionals.
Risk-averse culture	Organisations that distrust failure tend to resist change.	Reluctance to adopt disruptive technologies such as telemedicine.
Distrust in technologies	Lack of understanding of the benefits of new technologies.	Resistance to remote monitoring software by healthcare professionals.
Organisational barriers		
Lack of training	The absence of training programmes hinders adaptation to new technologies.	Healthcare professionals without adequate training in new technological systems.
Weak leadership	Lack of visionary leadership to guide the team in the transition to innovation.	Management is unable to prioritise and clearly communicate the importance of innovations.
Insufficient resources	Lack of funding and adequate infrastructure limits implementation.	Hospitals with low budgets for the acquisition and installation of telemedicine systems.
Overcoming barriers		
Continuous training	Invest in adequate training for healthcare professionals.	Implement regular training programmes for the use of assistive devices.
Clear leadership	Clearly communicate the benefits of new technologies.	Leadership that explains the positive impact of innovation on patients and organisational efficiency.
Culture of innovation	Promote a culture open to change and experimentation.	Encourage the experimental use of AI with technical support, followed by outcome analysis.
Gradual implementation	Introduce technologies progressively, with ongoing technical support.	Adopt telemedicine initially in specific departments before expanding across the entire organisation.

Source: Own elaboration, adapted from Herzlinger (2006), Greenhalgh et al. (2017), Kim and Lee (2022), Johnson and Martinez (2024), and Nguyen (2024).

Table 1 summarises the main barriers to the adoption of technological innovation in rehabilitation nursing, highlighting cultural, organisational, and infrastructural dimensions. This categorisation is consistent with classical analyses, such as Herzlinger (2006), who emphasises the difficulty of cultural change in the healthcare sector, and Greenhalgh et al. (2017), who underline the challenges of sustainability in technological adoption. More recently, studies such as Kim and Lee (2022) and Johnson and Martinez (2024) reinforce the idea that organisational resistance and the absence of clear leadership are central obstacles, while Nguyen (2024) and Lee and Patel (2024) point to the need for continuous training as an essential strategy to overcome these barriers.

Kwak and Lee (2022) suggest that, with adequate leadership and sustained support, the barriers to technological innovation can be overcome, resulting in improvements in patient care and efficiency within healthcare organisations. Chheang et al. (2023) further stress that personalisation of care, when integrated with innovative technologies, can significantly enhance both the efficiency and the effectiveness of services.

The identification of specific niches within healthcare services also emerges as a promising solution. According to Herzlinger (2006), adapting resources and strategies to meet the needs of different groups of patients is an underutilised yet highly valuable approach in the context of rehabilitation nursing.

Finally, effective management in the healthcare sector must go beyond achieving operational results, requiring flexibility, strategic vision, and the capacity to respond swiftly to legislative and clinical changes. Managerial resilience thus becomes an indispensable competence, enabling organisations to maintain a consistent focus on patient needs even in dynamic and unpredictable environments. Moktadir et al. (2018) address the survival of supply chains in the era of Industry 4.0, highlighting the need to adapt to new technologies to ensure resilience and operational efficiency. Their analysis illustrates how digitalisation, automation, and artificial intelligence can optimise hospital logistics, reduce waste, and ensure agile responses to healthcare crises. This balance between innovation and adaptation is crucial to ensuring that rehabilitation services not only keep pace with change but also lead transformations within the sector.

2.1. Innovation in Rehabilitation Nursing

Healthcare innovation must be patient-oriented, encouraging active participation in the definition and evaluation of care. Herzlinger (2006) emphasises that patient-centred innovation is crucial for ensuring effectiveness, informed choice, and satisfaction in contemporary healthcare systems.

Innovation plays an essential role in transforming and enhancing the quality of care delivered in rehabilitation nursing. Emerging technologies such as telemedicine and assistive devices have made a significant contribution to the personalisation and optimisation of treatments, resulting in improved clinical outcomes. For example, telemedicine facilitates remote monitoring and continuity of care, enabling professionals to follow patients more effectively (Dinesen et al., 2016). Likewise, robotic therapy and artificial intelligence have revolutionised rehabilitation treatments, offering more personalised and efficient approaches (Maciejasz et al., 2014; Wong, Leung & Wang, 2020).

These technological innovations not only increase the efficiency of treatments but also create opportunities for recovery and patient satisfaction, as highlighted by Topol (2019). Innovation in the healthcare sector operates bilaterally: while it drives the development of new technologies, these also create opportunities to transform the sector. Khatib et al. (2021, *Technological Forecasting & Social Change*) investigate the relationship between digital transformation and financial sustainability, stressing how emerging technologies such as big data and advanced algorithms can optimise financial management in healthcare. The implementation of predictive analytics and financial automation tools may be particularly relevant for hospitals and clinics integrating wearable medical devices and telemedicine solutions, thereby ensuring a viable and competitive business model.

2.1.1. Authors' Perspectives on Innovation

The table below summarises the main contributions from recent literature on innovation in the context of rehabilitation nursing.

Table 2: Authors and Perspectives on Innovation.

Author(s) and Year	Perspective on Innovation
Gómez-Jorge et al. (2025)	They discuss how business innovations, particularly in healthcare start-ups, provide creative solutions to challenges in rehabilitation. In rehabilitation nursing, this translates into the use of technologies and innovative processes aimed at improving patient outcomes.
Wang et al. (2024)	They argue that telemedicine has the potential to transform rehabilitation care, making it more accessible and effective.
(Wong, Leung & Wang, 2020)	They highlight the use of artificial intelligence and robotics as crucial innovations for personalising treatments and enhancing efficiency in patient recovery.
Lee & Kim (2022, *BMC Medical Informatics and Decision Making*)	They point out that barriers to innovation can be overcome with strategies that include adequate training and organisational support, which are essential for implementing new technologies in rehabilitation nursing.
Keesara et al. (2020, *New England Journal of Medicine*)	They emphasise the importance of directing innovation towards specific niches, ensuring that emerging technologies meet the concrete needs of patient groups. In rehabilitation nursing, this may include the personalisation of assistive devices for different clinical conditions.

Source: Adapted from Gómez-Jorge et al. (2025), Wong, Leung & Wang (2020), Lee & Kim (2022), Keesara et al. (2020), Greenhalgh et al. (2017), and Herzlinger (2006).

Table 2 indicates that authors broadly agree on the value of technological innovation as a driver of transformation in rehabilitation nursing, highlighting solutions such as telemedicine, artificial intelligence, robotics, and entrepreneurship. Divergences emerge mainly in emphasis: while some advocate for technological expansion, others stress the importance of overcoming organisational and cultural barriers, ensuring adequate training and adaptation to the specific needs of patients.

2.1.2. Humanisation and Technology: The Necessary Balance

Alves et al. (2024), in a systematic review published in *Heliyon*, examine outcomes from structured home-based rehabilitation programmes for older adults, highlighting clinical benefits and implications for the digital empowerment of patients and nursing teams. The study also highlights the opportunities and challenges of AI adoption in nursing practice, including ethical barriers, professional training, and technological acceptance — all essential aspects for the strategic development of new solutions in healthcare.

The focus must remain on improving the relationship between patient and healthcare professional, promoting empathy and humanised care. Wong, Leung and Wang (2020) argue that the use of AI and robotics should be accompanied by strategies ensuring that technology acts as a facilitator of care, rather than as a barrier.

Furthermore, Topol (2019) emphasises that while technological innovation can enhance efficiency, the patient must remain at the centre of the process, ensuring that new tools serve as support mechanisms for humanised care. This balance is fundamental for turning technological challenges into genuine opportunities for improving rehabilitation care, promoting not only clinical advances but also a more satisfactory patient experience.

2.2. Entrepreneurship in the Healthcare Domain

Entrepreneurship is regarded as an effective approach for fostering innovation and improving the management of healthcare services, including rehabilitation.

Leite et al. (2024) provide key insights into how entrepreneurship can be applied in healthcare, using technological innovations to develop new services and products that address emerging needs in rehabilitation.

Similarly, Mauro et al. (2024, *Technological Forecasting & Social Change*) support the view that entrepreneurship-driven innovation is essential for expanding access to rehabilitation treatments, highlighting how start-ups can offer tailored solutions for diverse patient needs.

Other authors, such as Chheang et al. (2023), contribute by discussing how entrepreneurship can support the development of care models based on AI and robotics, two promising areas within rehabilitation nursing.

Kwak and Lee (2022) stress that entrepreneurship-driven innovation must include strategies to overcome organisational resistance, which is crucial for introducing new practices and technologies in rehabilitation nursing.

Walden et al. (2020, *Journal of Clinical and Translational Science*) argue that entrepreneurship in healthcare can identify profitable niches within rehabilitation services, such as assistive technologies, and expand the market reach of these innovations.

Entrepreneurship in healthcare has long been viewed as a way of stimulating innovation, but today it is more critical than ever, as noted by Leite et al. (2024). It can serve as a mechanism for breaking bureaucratic barriers that often hinder the rapid implementation of new ideas in healthcare. However, it is vital that entrepreneurship in this field is guided by strong ethical principles and ultimately aims at patient well-being.

In this regard, Gómez-Jorge, Bermejo-Olivas, Díaz-Garrido, and Soriano-Pinar (2025), in the *International Entrepreneurship and Management Journal*, analyse the impact of self-esteem and entrepreneurial orientation on success in healthcare entrepreneurship. Their study underscores how healthcare professionals' confidence and entrepreneurial vision can be decisive in implementing innovative solutions, stressing the importance of promoting entrepreneurial training within healthcare management to achieve sustainable and effective impact.

More recently, Gkiolnta et al. (2025) focus on the role of innovations in rehabilitation, advocating that technological adoption must be accompanied by ethical analysis and practical assessment of its impact on care. While many start-ups have invested in innovative technological solutions, the authors stress that this approach must be balanced with a human-centred vision of care, ensuring that innovations are not only economically viable but also practical and effective in everyday rehabilitation settings.

3. Methodology

This study adopts a qualitative exploratory approach, structured as a narrative literature review complemented by the analysis of practical cases. The choice of a narrative review is justified by the multidimensional complexity of technological innovation in rehabilitation nursing and the need to integrate different types of sources (scientific articles, institutional reports, and regulatory documents), without the rigidity of systematic protocols (Creswell, 2014).

3.1. Methodological Structure

Scope, sources, descriptors, criteria, and case logic. We conducted a narrative literature review across PubMed, Scopus, Web of Science, and national resources (RCAAP, SciELO Portugal), complemented by Google Scholar for institutional/grey literature, covering 2020–2025 and including works in Portuguese or English. We combined descriptors such as nursing innovation, rehabilitation nursing, digital health, entrepreneurship in nursing, and artificial intelligence with Boolean operators. Inclusion criteria comprised peer-reviewed articles and official documents (e.g., ANI, WHO, UNESCO) relevant to technological innovation in rehabilitation nursing; exclusion criteria removed duplicates, non-peer-reviewed/opinion pieces, and purely technical documents without clinical linkage. To complement the review, we purposively selected two Portuguese cases—Subcutaneous Hydration Device (DHS) and DigiNurse—based on theoretical relevance, prior scientific validation/usability, and practical applicability to rehabilitation/home-palliative care and digital capacity-building, respectively; this corpus was then fed into the subsequent triangulation stage. The literature search was last updated on 20 September 2025.

3.1.1. Methodological Triangulation

The data obtained from the narrative literature review, and the case analysis were integrated through methodological triangulation (Flick, 2009). This procedure enabled the confrontation of theoretical concepts with empirical evidence, strengthening the validity of the findings and highlighting convergences and contradictions across different contexts.

3.2. Justification of the Research Design

The decision to adopt a qualitative and narrative approach was intentional, as the aim was not to quantify effects but rather to interpret practices, meanings, and organisational resistances related to innovation in healthcare. Although the term *review* is used, this study does not follow formal systematic protocols such as PRISMA, but is guided by principles of narrative, reflexive, and critical rigour.

To ensure consistency, inclusion and exclusion criteria were made explicit, and transparent procedures were adopted for the selection and analysis of sources. In this way, the study aligns with recognised quality practices inspired by COREQ, even though it does not constitute a systematic review. Future research may adopt more formal methodologies (e.g., PRISMA or mixed-method protocols) to reinforce the robustness and replicability of the findings.

4. Presentation and Discussion of Results

Rehabilitation nursing has been significantly transformed by the advancement of digital technologies and the growing demand for personalised care. The literature reviewed reveals a broad consensus regarding the potential of technological innovation to optimise clinical outcomes, enhance organisational efficiency, and respond to patients' needs with greater precision (Leite et al., 2024; Mauro et al., 2024; Wong, Leung & Wang, 2020). Technologies such as artificial intelligence (AI), robotics, and telemedicine have proven to be essential tools for tailoring care, particularly for populations with specific needs, such as patients with visual impairment, neurological injuries, or complex chronic conditions (Maciejasz et al., 2014).

The authors' critical analysis, however, highlights tensions and divergences. On the one hand, there is an optimistic discourse surrounding emerging technologies; on the other, structural, cultural, and ethical barriers to their implementation persist. Kwak and Lee (2022) emphasise the importance of addressing organisational resistance and professional culture as tangible obstacles to change, echoing Mintzberg's (1979) classic analysis of organisational structures in highly professionalised contexts.

A central contribution of this study lies in valuing not only international institutional practices (e.g., Mayo Clinic, Cleveland Clinic) but also national experiences, such as *GerenciaDOR* — a digital tool developed in Portugal for the personalised management of chronic pain — and the innovation projects promoted by ANI and TecCare at the University of Coimbra. These experiences reveal that, although much of the discourse on technological innovation is imported from Anglo-Saxon contexts, there exists a local innovation capacity with high potential for scalability.

The analysis of the literature demonstrates convergence regarding the transformative potential of artificial intelligence and telemedicine, widely praised by authors such as Topol (2019), who underlines their disruptive impact on clinical practice. Nonetheless, significant contradictions also emerge, as other scholars, including Morley et al. (2020), warn of ethical risks and the insufficient institutional maturity for adopting such technologies. This tension between optimistic and critical perspectives underscores the need to analyse health innovation contextually and in a balanced way, avoiding both uncritical adherence and premature rejection. While authors such as Topol (2019) and Wong, Leung & Wang (2020) stress their transformative potential, others, including Morley et al. (2020) and Jobin et al. (2019), raise concerns about ethical issues, privacy risks, and institutional readiness. This duality highlights that innovation must be understood as a multifaceted phenomenon, where opportunities coexist with limitations, requiring a balance between technological enthusiasm and critical prudence.

At an operational level, technologies such as virtual reality (VR) and tele-rehabilitation systems, such as KiReS, have been successfully applied in neurological rehabilitation, enabling more motivating and effective interventions. Studies such as those by Chheang et al. (2023) and Idoko et al. (2024) document the benefits of these technologies in improving functional recovery and treatment adherence. The triangulation of data suggests that such solutions, when integrated with patient-centred practices and supported by appropriate ethical and training frameworks, contribute to more efficient and humanised rehabilitation.

Nevertheless, multiple challenges remain. Johnson and Martinez (2024) and Adler-Milstein and Huckman (2013) identify resistance to change, adoption costs, and a lack of professional training as major obstacles. The literature consistently indicates that innovation will only have a sustainable impact if accompanied by strategies for continuous capacity-building (Gajarawala & Pelkowski, 2021; Booth et al., 2021) and financial planning that supports infrastructure upgrades. In Portugal, many institutions within the National Health Service (SNS) face budgetary and technological constraints that hinder the adoption and review of such innovations, reinforcing the need for public policies to foster digital transformation.

Ethical issues emerge as a transversal axis of the analysis. Morley et al. (2020) and Jobin, Ienca, and Vayena (2019) warn of the risks associated with data privacy, the potential dehumanisation of care, and the lack of regulation adapted to new technological realities. These concerns must be addressed from the planning stages of innovations, not only at the implementation phase, requiring the establishment of multidisciplinary ethics committees and the adoption of international frameworks such as COREQ.

The case study analysis underscored the role of institutional leadership in promoting innovation. The Mayo Clinic, for instance, has invested heavily in AI for early diagnosis and remote monitoring, while the Cleveland Clinic prioritises data interoperability and surgical robotics. These experiences demonstrate that technology alone is insufficient: it is the organisational culture — grounded in continuous learning, participatory management, and openness to experimentation — that determines the success of innovations (Cosgrove, 2014; Furst, 2024).

Finally, it is essential to highlight the importance of aligning technological innovation with the principles of humanised care. Automation and data analysis should free up professionals' time to strengthen their relational presence with patients, as advocated by Mauro et al. (2024). In this sense, innovation becomes not only a technical tool but also an ethical and existential one, enabling care to become closer, more empathetic, and more effective. Beyond international experiences, it is crucial to acknowledge the concrete contributions developed within Portugal, which reinforce the local potential for significant clinical innovation.

4.1. National Experiences of Innovation in Nursing: The Case of the ESEnfC

In addition to international experiences, it is crucial to recognise the contributions developed within Portugal, which demonstrate the potential of the Portuguese ecosystem to generate clinically innovative solutions grounded in scientific evidence. Prominent in this scenario is the *Escola Superior de Enfermagem de Coimbra* (ESEnfC), which, through the *Health Sciences Research Unit: Nursing* (UICISA: E) and its innovation hub *TecCare*, has led highly relevant projects, supported by the National Innovation Agency (ANI) (UICISA: E, 2024; ANI, 2022).

Among these projects, the *Subcutaneous Hydration Device* (DHS) stands out, designed for palliative and home care. Its development followed principles of scientific prototyping and clinical usability assessment (Silva, Fernandes & Sousa, 2023). The device was tested in real-life contexts and has been cited as good practice in applied co-innovation (Martins et al., 2024). Such initiatives show that the Portuguese higher education system in nursing can produce innovative solutions anchored in the real needs of patients and professionals (Moura et al., 2023).

A central figure in this movement is Professor Pedro Parreira, whose leadership of the *Entrepreneurship Office* and the TecCare strategic axis has been decisive in consolidating the ESEnfC as a hub of health innovation. Parreira articulates academic entrepreneurship with applied research in technologies for rehabilitation nursing care, with both national and international impact. Projects such as *DigiNurse*, focused on developing digital

competences among students and professionals (Parreira, Santos-Costa & Graveto, 2021), and smart textiles for the prevention of pressure ulcers (Salgueiro-Oliveira, Parreira & Martins, 2023), exemplify this integrated, evidence-based approach.

The scientific output from these initiatives has been published in journals such as *Computers, Informatics, Nursing*, *Jerhub* and *Heliyon*, academically validating the ESEnfC's contributions to health innovation. Recent studies also highlight the importance of digital literacy and interoperability in sustaining technological adoption in clinical practice (Gonçalves, Parreira & Salgueiro-Oliveira, 2022).

These experiences reinforce that innovation goes beyond device development: it encompasses knowledge management, organisational sustainability, and the enhancement of nursing practice within the Portuguese context. Therefore, the inclusion of national examples in academic analyses of this nature is not only relevant but essential to support contextually adapted proposals and encourage innovative practices aligned with local realities.

The following table provides a comparative synthesis between international and Portuguese practices in technological innovation in rehabilitation nursing, identifying points of convergence and singularity in each context.

Table 3: Comparative examples of technological innovation in rehabilitation nursing: international vs. Portuguese contexts.

Type of Innovation	International Example	National Example (Portugal)	Expected Impact
AI in Diagnosis	Mayo Clinic: AI for fall screening and remote monitoring	ESEnfC/TecCare: Prototyping of AI-based systems for home care	Enhanced safety and continuous clinical surveillance
Tele-Rehabilitation	KiReS System — Spain	*GerenciaDOR* project — Portugal (digital management of chronic pain)	Reduced travel; improved treatment adherence
Robotics	Cleveland Clinic: assisted and surgical robots	In the embryonic stage, under development in university centres	Potential for complex motor rehabilitation
Assistive Devices	Idoko et al. (2024): sensors for motor training	DHS — Subcutaneous Hydration Device (ESEnfC/UICISA: E)	More effective palliative care
Innovation Management	Participatory culture (Cosgrove, 2014)	Hybrid ESEnfC/ANI models involving clinical and academic collaboration	Sustainability and institutional replicability
Digital Capacity-Building	WHO and European Union — digital health literacy	*DigiNurse* — digital skills training in nursing (Parreira et al., 2021)	Strengthening digital competences
Smart Textiles	USA/Japan: wearables for vital signs	Smart textiles for pressure ulcer prevention (Salgueiro-Oliveira et al., 2023)	Injury prevention; improved clinical monitoring

Source: Author's elaboration, based on Cosgrove (2014), Mauro et al. (2024), Chheang et al. (2023), Furst (2024), Idoko et al. (2024), Moura et al. (2023), Parreira et al. (2021), Salgueiro-Oliveira et al. (2023), Gonçalves et al. (2022), UICISA:E (2024).

The comparative analysis presented in Table 3 demonstrates that technological innovation in rehabilitation nursing is not confined to major international centres but finds meaningful expression in Portugal. The practices

of the ESEnfC reveal that academic entrepreneurship, when aligned with scientific research and inter-institutional collaboration, can generate solutions with tangible and measurable impact. This finding reinforces the need to view the national context as an active agent in knowledge production and in the transformation of healthcare.

4.2. Critical Discussion

The analysis developed in this article shows that the challenges of technological innovation in rehabilitation nursing are transversal yet assume specific nuances depending on organisational and cultural contexts. In the United States and Japan, digital maturity is more advanced, characterised by the consolidated integration of artificial intelligence and robotics (Christensen, Grossman & Hwang, 2009; Furst, 2024). In countries such as Portugal, while infrastructural constraints and limited investment persist, the active role of academic institutions in generating applied and contextualised innovation is particularly noteworthy (Parreira, Santos-Costa & Graveto, 2021).

The case of the *Escola Superior de Enfermagem de Coimbra* (ESEnfC) is exemplary in this regard. Projects such as *DigiNurse*, the *Subcutaneous Hydration Device* (DHS), and smart textiles for the prevention of pressure ulcers have not only resulted in clinical prototypes but have also been validated in international publications, demonstrating the capacity of the Portuguese academic ecosystem to produce evidence-based and relevant solutions (Salgueiro-Oliveira, Parreira & Martins, 2023; Gonçalves, Parreira & Salgueiro-Oliveira, 2022). The articulation between research, clinical practice, and strategic management constitutes a distinguishing feature that can inspire hybrid models of innovation in other regions, bridging science, education, and care.

Despite these advances, the generalisation of such practices faces obstacles such as fragmented funding policies, disparities in professionals' digital literacy, and the absence of interoperable systems. The literature further warns of the risk of innovation becoming overly focused on technical performance to the detriment of humanised care (Guarducci et al., 2025). Striking a balance between technological efficiency and relational dimensions is particularly crucial in rehabilitation nursing, where the therapeutic relationship is an essential component of the recovery process (Moura et al., 2023).

Finally, it is important to acknowledge the methodological limitations of this study. As a narrative literature review, its purpose is not exhaustiveness but rather the construction of an integrated and critical analysis. This approach has enabled the mapping of trends, the identification of transformative experiences, and the proposal of theoretical-practical pathways for reflection. Future research should adopt mixed methodologies — incorporating interviews with professionals, focus groups, and clinical and organisational impact analyses — as well as broader international comparisons, to validate and consolidate sustainable models of innovation in rehabilitation nursing.

Conclusion

This study investigated the challenges and opportunities of technological innovation in rehabilitation nursing, integrating international literature and national experiences, with particular emphasis on the projects of the *Escola Superior de Enfermagem de Coimbra* (ESEnfC), in partnership with the ANI and UICISA: E. The original contributions of this work are centred on three dimensions: (i) the systematic identification of facilitators and barriers — cultural, organisational, and infrastructural — that shape technological innovation in rehabilitation; (ii) the valorisation of validated national examples, such as *DigiNurse*, the *Subcutaneous Hydration Device* (DHS), and smart textiles for the prevention of pressure ulcers, which demonstrate Portugal's capacity to generate applicable and contextualised solutions; and (iii) the defence of hybrid models that combine technological innovation, strategic management, and humanisation as an essential condition for sustainable, person-centred practices.

The analysis highlighted convergences in the literature regarding the potential of artificial intelligence, tele-rehabilitation, and assistive devices to personalise care and optimise resources, while also underlining divergences in institutional levels of technological maturity and the ethical implications associated with their use.

Such differences reinforce the importance of critical approaches that consider specific organisational, pedagogical, and cultural contexts.

The limitations of this study include the exploratory and narrative nature of the review, the absence of quantitative empirical data, and the restricted timeframe (2020–2025). Nevertheless, the analysis enabled the mapping of trends, convergences, and contradictions, providing a solid basis for both theoretical and practical reflection. Future research should adopt mixed methodologies — such as interviews, focus groups, and clinical and organisational impact studies — and align with frameworks such as COREQ, to strengthen the robustness and replicability of the findings.

In summary, this study concludes that innovation in rehabilitation nursing should not be understood as a mere technological product, but rather as a cultural, pedagogical, and strategic process. The Portuguese experience, illustrated by the work of the ESEnfC, demonstrates that academic entrepreneurship, when combined with transformational leadership and integrated management, can serve as a driving force for sustainable and humanised care transformation, making a significant contribution to nursing science, health management, and the modernisation of care systems in Portugal and on the global stage.

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