

Review

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Hard technologies for prevention of pressure injuries in hospitalized adults and older adults: a scoping review.

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Hard technologies for prevention of pressure injuries in hospitalized adults and older adults: a scoping review

Tecnologias duras para prevenção de lesão por pressão em adultos e idosos hospitalizados: revisão de escopo

Tecnologías duras para prevención de lesiones por presión en adultos y ancianos hospitalizados: una revisión exploratória

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ABSTRACT

Objective: To map hard technologies for the prevention of pressure injuries in hospitalized adults and older adults.

Method: A scoping review following JBI methodology and PRISMA-ScR guidelines, searching the following databases: LILACS and BDENF (via VHL), MEDLINE, SCOPUS, CINAHL, and Embase. Gray literature was consulted via the Brazilian Digital Library of Theses and Dissertations. The protocol was registered on the Open Science Framework. Screening and analysis were conducted blindly and independently by two reviewers, with a third reviewer resolving any conflicts. Data were extracted using a JBI-adapted instrument and analyzed through descriptive and narrative synthesis.

Results: A total of twenty-one studies (2013-2025) with varying levels of evidence were included. Identified technologies included wireless wearable sensors, pressure-redistribution devices, machine learning-based predictive models, continuous monitoring systems, moisture scanners, thermography, and deep tissue ultrasound. Wearable sensors increased adherence to repositioning; predictive models achieved an $AUC \geq 0.80$; and early detection technologies identified tissue damage.

Final considerations: The mapped technologies demonstrated potential for the early detection of tissue changes, increased adherence to repositioning, and risk prediction, offering the prospect of contributing to a reduction in the incidence of pressure injuries.

Descriptors: Technology; Pressure injury; Prevention; Hospital; Patient safety.

RESUMO

Objetivo: mapear as tecnologias duras para a prevenção de lesão por pressão em adultos e idosos hospitalizados.

Método: revisão de escopo segundo metodologia JBI e diretrizes PRISMA-ScR, com busca nas bases de dados: LILACS e BDENF via BVS, MEDLINE, SCOPUS, CINAHL e Embase. Consulta da literatura cinzenta na Biblioteca Digital Brasileira de Teses e Dissertações. O protocolo foi registrado no *Open Science Framework*. A triagem e a análise ocorreram de forma cega e independente, por dois revisores, com resolução de conflitos por terceiro revisor. Dados extraídos com instrumento adaptado do JBI e analisados por síntese descritiva e narrativa.

Resultados: 21 estudos analisados (2013-2025), com variação de níveis de evidência. Identificou-se tecnologias como sensores vestíveis sem fio, dispositivos de redistribuição de pressão, modelos preditivos baseados em aprendizado de máquina, sistemas de monitoramento contínuo, *scanner* de umidade, termografia e ultrassonografia de tecido profundo. Sensores vestíveis elevaram a adesão ao reposicionamento; modelos preditivos alcançaram $AUC \geq 0,80$; tecnologias de detecção precoce identificaram dano tecidual.

Considerações finais: as tecnologias mapeadas mostraram potencial para detecção precoce de alterações teciduais, o aumento da adesão ao reposicionamento e predição de risco, com perspectiva de contribuir para a redução da incidência de lesão por pressão.

Descritores: Tecnologia. Lesão por pressão; Prevenção; Hospital; Segurança do paciente

RESUMEN

Objetivo: Mapear las tecnologías sanitarias para la prevención de úlceras por presión en adultos y ancianos hospitalizados.

Método: Se realizó una revisión exploratoria utilizando la metodología JBI y las directrices PRISMA-ScR, buscando en las siguientes bases de datos: LILACS y BDENF a través de BVS, MEDLINE, SCOPUS, CINAHL y Embase. También se consultó literatura gris en la Biblioteca Digital Brasileña de Tesis y Disertaciones. El protocolo se registró en Open Science Framework. La selección y el análisis fueron realizados de forma ciega e independiente por dos revisores, con resolución de conflictos por un tercer revisor. Los datos

se extrajeron utilizando un instrumento adaptado de JBI y se analizaron mediante síntesis descriptiva y narrativa.

Resultados: Se identificaron 21 estudios publicados (2013-2025), con diferentes niveles de evidencia. Se identificaron tecnologías como sensores portátiles inalámbricos, dispositivos de redistribución de presión, modelos predictivos basados en aprendizaje automático, sistemas de monitorización continua, escáneres de humedad, termografía y ultrasonido de tejidos profundos. Los sensores portátiles mejoraron la adherencia al reposicionamiento; los modelos predictivos alcanzaron un $AUC \geq 0,80$; y las tecnologías de detección temprana identificaron daños tisulares.

Consideraciones finales: las tecnologías identificadas mostraron potencial para la detección temprana de cambios tisulares, una mayor adherencia al reposicionamiento y la predicción de riesgos, con la perspectiva de contribuir a la reducción de la incidencia de úlceras por presión.

Descriptores: Tecnología; Lesión por presión; Prevención; Hospital; Seguridad del paciente.

INTRODUCTION

Pressure injuries (PIs) generally develop over bony prominences as a result from sustained pressure or a combination of pressure with shear and friction forces, causing progressive damage to the underlying tissues⁽¹⁾. Their prevention in hospitalized patients is a priority in contemporary clinical practice⁽²⁾, requiring the early identification of risk factors and the implementation of effective care practices⁽³⁻⁴⁾.

Risk factors associated with the development of PIs may be intrinsic, such as advanced age, comorbidities, nutritional status, hydration, mobility, and level of consciousness, or extrinsic, including pressure, shear, friction, and moisture⁽³⁾. Assessment of these factors must be contextualized through clinical judgment, considering the patient's condition and history, so that preventive measures can be implemented effectively and individually⁽⁴⁾.

In the hospital setting, PIs are recognized as adverse events associated to healthcare, with a direct impact on increased length of stay, morbidity and mortality rates, and patient quality of life⁽⁵⁾. Globally, the incidence rate of these injuries is 5.4 per 10,000 hospital days, with a prevalence of 12.8%, affecting 8.5% of hospitalized adult patients⁽⁶⁾.

The economic impact of these injuries is also substantial. In Australia, the mean length of hospital stay for patients with PIs ranges from 4.3 days, with an estimated cost of AU\$699 to AU\$840 per day of hospitalization⁽⁷⁾. In Brazil, in 2020 alone, expenditures on hospitalizations resulting from PIs exceeded R\$19 million, representing 1% of total healthcare expenditures in the Unified Health System (*Sistema Único de Saúde* - SUS), and may reach up to 5% in other healthcare systems⁽⁸⁾.

In this context, technologies aimed at preventing PI have emerged as strategies capable of improving work processes, expediting risk identification, and supporting clinical decision-making⁽⁹⁻¹⁰⁾. The classification of technologies adopted in this review follows the framework proposed by Merhy⁽¹¹⁾, which categorizes them into three types: light (relationship building, welcoming, and promotion of autonomy), light-hard (structured knowledge that transforms work processes), and hard (equipment, devices, standards, and organizational structures).

This study focuses on hard technologies. This is an authorial position grounded in Merhy's framework⁽¹¹⁾, according to which hard technologies represent a set of innovations that can be objectified, measured, and compared across different care settings, thus constituting a relevant field for mapping evidence on PI prevention in hospital settings.

An integrative review of technologies implemented for PI prevention in the Brazilian hospital setting found that the available evidence remains scarce and heterogeneous, characterized with a predominance of studies with low levels of evidence and a lack of comprehensive mapping of technologies available internationally⁽¹²⁾. This gap highlights the relevance of a scoping review to systematically and up-to-date map the technologies available for PI prevention, with the aim of contributing to evidence-based clinical practice, identifying gaps for innovation, and strengthening the safety of hospitalized patients.

Based on the foregoing, this study aims to map hard technologies for PI prevention in hospitalized adults and older adults.

METHOD

This is a scoping review conducted in compliance with the methodology proposed by the JBI⁽¹³⁾ and the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols, extension for Scoping Reviews (PRISMA-ScR)⁽¹⁴⁾. The protocol for this review was registered in the Open Science Framework (OSF) with DOI <https://doi.org/10.17605/OSF.IO/8NRFX>.

The search was conducted between October 2024 and January 2025. In October 2025, a structured supplementary search was conducted to update the results, rigorously following the same strategies, data sources, and criteria adopted in the initial search.

To formulate the review question, the PCC (Population, Concept, and Context) strategy was adopted: Population (hospitalized adult and older adult patients), Concept (hard technologies for PI prevention), and Context (hospital setting). Thus, the review question was

formulated as follows: What evidence is available in the literature on hard technologies used for PI prevention in hospitalized adults and older adults?

Inclusion criteria comprised primary studies and literature reviews addressing hard technologies for PI prevention; publications involving adult patients aged 18 years or older and hospitalized older adults, regardless of the pathology or reason for hospitalization; and studies conducted in hospital settings. All methodological designs were eligible, including experimental, quasi-experimental, observational, and descriptive studies, as well as systematic, integrative, and scoping reviews, with no language or time restrictions. The delimitation to the adult and older adult age groups was based on the specific risk profile for PI in this population, characterized by a higher prevalence of immobility, comorbidities, and frailty, as well as the greater availability of evidence on preventive technologies targeting this group, as identified during the search process.

The exclusion criteria were studies focused exclusively on PI treatment, without a preventive component; educational interventions directed at healthcare professionals without assessment of patient outcomes; literature reviews without data on specific technologies; studies for which the full text was inaccessible; duplicate publications; and articles from journals identified as potentially predatory, as verified using the international Predatory Journals list (<https://www.predatoryjournals.org/the-list/journals>), due to their potential to compromise the reliability of the mapped evidence.

The review was conducted using the following data sources: Latin American and Caribbean Literature in Health Sciences (LILACS), Nursing Database (BDENF) via the Virtual Health Library (VHL), Medical Literature Analysis and Retrieval System Online/National Library of Medicine (MEDLINE/PubMed), SCOPUS, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Embase, and, as a source of grey literature, the Brazilian Digital Library of Theses and Dissertations (*Biblioteca Digital Brasileira de Teses e Dissertações* - BDTD). A cross-reference search was also performed by examining the reference lists of the articles to identify additional potentially relevant studies.

Controlled descriptors from the following vocabularies were used: *Descritores em Ciências da Saúde* (DeCS*), Medical Subject Headings (MeSH), CINAHL Headings, and Emtree. Initially, a preliminary search was conducted in MEDLINE/PubMed and Google Scholar, using the descriptors defined by the PCC framework, with the aim of identifying terms present in the titles, abstracts, and indexing of the articles. Based on the terms retrieved, search strategies were developed that included descriptors and synonyms selected according to their relevance to the study. The terms were combined using the Boolean operators AND

and OR. The search strategy was developed in five stages: extraction, conversion, combination, construction, and application, as described in one study on reviews⁽¹⁵⁾. The search strategies are presented in Chart 1.

Chart 1 - Development of the search strategy in the databases and grey literature. Teresina (PI), Brazil, 2025

Database	Search strategy
LILACS /BDENF	((mh:("Úlcera por Pressão")) OR (mh:("Úlcera por Presión")) OR (mh:("Pressure Ulcer"))) OR ("Lesão por Pressão") OR ("Escara de Decúbito") OR ("Úlcera de Decúbito") OR ("Úlcera de Pressão") OR ("Úlceras por Pressão") OR ("Escara de Pressão") OR ("Escaras de Pressão") OR ("Úlceras de Decúbito") OR ("Lesión por presión") OR ("llaga de decúbito") OR ("Úlcera de decúbito") OR ("Úlcera por presión") OR ("Úlceras por presión") OR ("Úlcera por presión") OR ("Úlceras por presión") OR ("Úlceras por presión") OR ("Pressure Ulcers") OR ("Ulcer, Pressure") OR ("Bed Sores") OR ("Bed Sore") OR ("Sore, Bed") OR (bedsore) OR (bedsores) OR ("Decubitus Ulcer ") OR ("Decubitus Ulcers") OR ("Ulcer, Decubitus") OR ("Pressure Sore") OR ("Pressure Sores") OR ("Sore, Pressure") OR ("Decubitus Sore") OR ("Decubitus Sores") OR ("Sore, Decubitus") OR ("Pressure Injury") OR ("Injury, Pressure") OR ("Pressure Injuries")) AND ((mh:(tecnologia)) OR (mh:(tecnología)) OR (technology) OR (tecnologias)) AND ((mh:(hospitais)) OR (mh:(hospitales)) OR (mh:(hospitals)) OR (hospitais) OR ("Centro Hospitalar") OR ("Centros Hospitalares") OR (hospital) OR (nosocômio) OR (nosocômios) OR ("Ambiente Hospitalar") OR (hospitales) OR ("Centro hospitalario") OR ("Centros Hospitalarios") OR (nosocomio) OR (nosocomios) OR ("Ambiente hospitalário")) AND db:("LILACS" OR "BDENF") AND instance:"regional"
MEDLINE	("Pressure Ulcer"[MeSH Terms] OR "Pressure Ulcers"[All Fields] OR "ulcer pressure"[All Fields] OR "Bed Sores"[All Fields] OR "Bed Sore"[All Fields] OR "sore bed"[All Fields] OR "Bedsore"[All Fields] OR "Decubitus Ulcer"[All Fields] OR "Decubitus Ulcers"[All Fields] OR "ulcer decubitus"[All Fields] OR "Pressure Sore"[All Fields] OR "Pressure Sores"[All Fields] OR "sore pressure"[All Fields] OR "Decubitus Sore"[All Fields] OR "Decubitus Sores"[All Fields] OR "sore decubitus"[All Fields] OR "Pressure Injury"[All Fields] OR "injury pressure"[All Fields] OR "Pressure Injuries"[All Fields]) AND ("technology"[MeSH Terms] OR "technology"[All Fields] OR "technologies"[All Fields] OR "technology s"[All Fields]) AND ("hospitals"[MeSH Terms] OR "hospital s"[All Fields] OR "hospitalisation"[All Fields] OR "hospitalization"[MeSH Terms] OR "hospitalization"[All Fields] OR "hospitalised"[All Fields] OR "hospitalising"[All Fields] OR "hospitality"[All Fields] OR "hospitalisations"[All Fields] OR "hospitalizations"[All Fields] OR "hospitalize"[All Fields] OR "hospitalized"[All Fields] OR "hospitalizing"[All Fields] OR "hospitals"[MeSH Terms] OR "hospitals"[All Fields] OR "hospital"[All Fields])
SCOPUS	(TITLE-ABS-KEY ("pressure ulcer") OR TITLE-ABS-KEY ("pressure

	maternity'/exp OR 'hospitals, maternity' OR 'hospitals, osteopathic'/exp OR 'hospitals, osteopathic' OR 'hospitals, packaged'/exp OR 'hospitals, packaged' OR 'hospitals, proprietary'/exp OR 'hospitals, proprietary' OR 'hospitals, satellite'/exp OR 'hospitals, satellite' OR 'hospitals, special'/exp OR 'hospitals, special' OR 'hospitals, state'/exp OR 'hospitals, state' OR 'infirmary'/exp OR 'infirmary' OR 'medical clinic'/exp OR 'medical clinic' OR 'regional hospital'/exp OR 'regional hospital' OR 'state hospital'/exp OR 'state hospital' OR 'hospital'/exp OR 'hospital')
BDTD*	(All fields: " <i>Lesão por Pressão</i> " OR " <i>Úlcera por pressão</i> " AND All fields: <i>Tecnologias</i> OR <i>tecnologia</i> AND All fields: <i>hospitais</i> OR hospital)

*BDTD: Brazilian Digital Library of Theses and Dissertations.

Source: Prepared by the authors (2025).

The selection of relevant materials was conducted using the Rayyan Qatar Computing Research Institute (QCRI) Systems reference management tool. After exporting the records from the consulted information sources, two reviewers (FCSAGB and MCSS), working independently, performed duplicate removal. The publications were then included or excluded based on title and abstract screening; those retained were read in full and assessed according to the previously established criteria. The procedure was conducted in a blinded manner using the blind on functionality available in the system. Disagreements between the reviewers were managed by a third reviewer (EVP), who provided a decision regarding the inclusion and/or exclusion of studies in conflict. The entire process was summarized in the PRISMA-ScR flowchart (Figure 1).

Data extraction from the eligible studies was performed independently and in duplicate by two reviewers (FCSAGB and MCSS), using a data collection instrument adapted from the JBI model for scoping reviews⁽¹³⁾. The tool was tested on three pilot articles to calibrate the reviewers before formal extraction. Disagreements were resolved by consensus or, when necessary, by a third reviewer (EVP). The extracted variables included authorship, year of publication, country of origin, study design, identification of the technology (type, characteristics, and functioning), target population, main findings, reported barriers, and limitations.

Although scoping reviews generally do not explicitly recommend critical appraisal of the texts, the classification of studies by level of evidence was arbitrarily adopted in this review to characterize the methodological profile of the mapped body of evidence, in order to provide readers with an overview of the scientific maturity of the identified technologies and to support future recommendations for clinical practice. This characterization followed the JBI hierarchy^(13,16), which categorizes studies into five levels: Level 1 (experimental), Level 2 (quasi-experimental), Level 3 (analytical observational), Level 4 (descriptive observational),

and Level 5 (expert opinion). For studies that did not directly fit the categories provided, such as scoping reviews and integrative reviews included in the sample, the underlying study design was analyzed and classified at the most appropriate level of the JBI hierarchy, in accordance with the guidance provided in the manual itself. This methodological decision was recorded and documented in the data extraction instrument. This classification allows the strength of the available evidence on the mapped technologies to be identified, although it does not represent a critical appraisal of the methodological quality of the studies, which is inherent to the nature of scoping reviews.

Data synthesis was conducted using a descriptive and narrative approach, in accordance with the JBI methodological recommendations for scoping reviews. In the first stage, the extracted data were organized and tabulated according to predefined categories: type of technology, target population, clinical setting, study design, main findings, and barriers/limitations. In the second stage, a comparative analysis of the studies was performed to identify similarities, differences, patterns of evidence, and knowledge gaps.

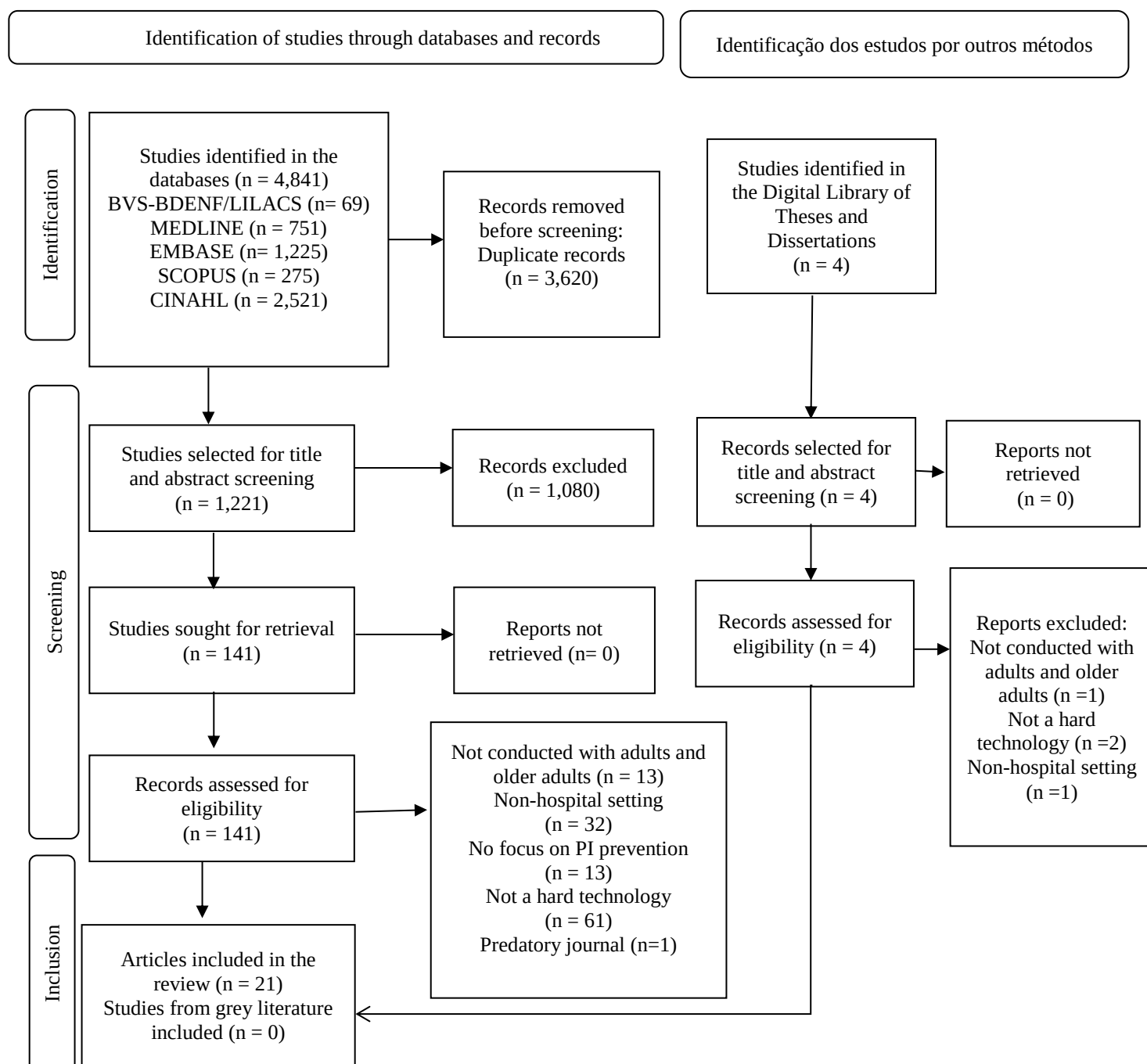
The results were presented through tables and figures developed by the authors. Figure 3, designed to graphically represent the categories, mechanisms of action, and similarities among the identified technologies, was developed with the support of a generative artificial intelligence tool (ChatGPT, OpenAI, version 5.0), used exclusively to support the visual organization of the information. All content presented underwent critical review, validation, and final approval by the researchers.

This study is based on the analysis of secondary data, thereby obviating the need for submission to a Research Ethics Committee (REC), in accordance with Resolution No. 466/12.

RESULTS

A total of 4,841 articles were identified in the databases, of which 3,620 duplicates were excluded, leaving 1,221 records for title and abstract screening. After the initial screening based on title and abstract review, 1,080 studies were excluded, and 141 were selected for full-text assessment. Of these, 119 were excluded because they did not address the research question. The final sample comprised 21 articles^(9-10,12,17-34), as shown in Figure 1.

Figure 1 - PRISMA-ScR flowchart of study selection. Teresina (PI), Brazil, 2025.

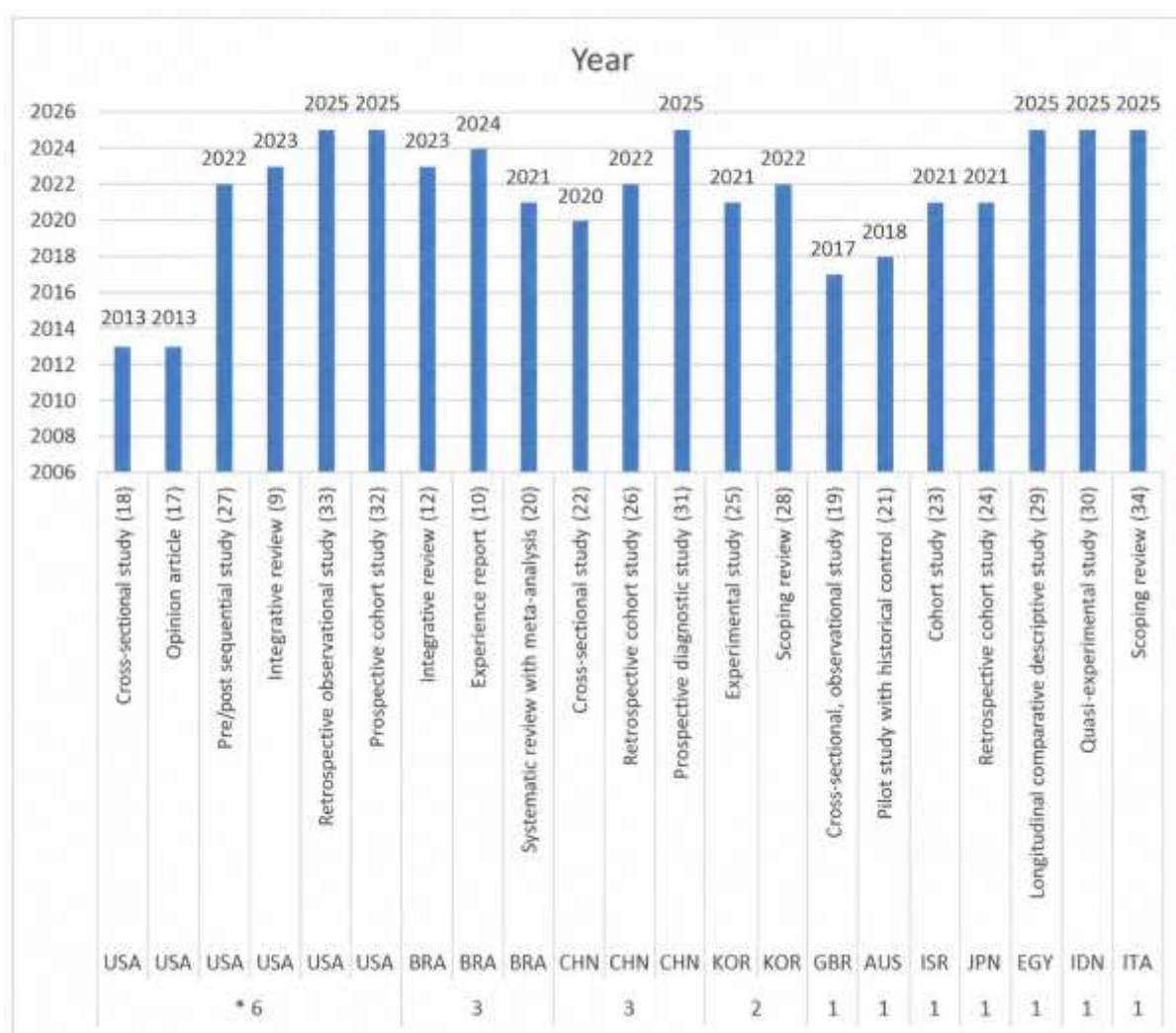


Source: Prepared by the authors (2025), adapted from PRISMA-ScR⁽¹⁴⁾.

The temporal distribution of the 21 included studies (2013–2025) shows a significant increase in publications from 2022 onward, reflecting recent scientific interest in technological solutions for PI prevention (Figure 2). The studies were conducted in 11 countries, predominantly the United States (n = 6)^(9,17-18,27,32-33), followed by Brazil (n = 3)^(10,12,20) and China (n=3)^(22,26,31). Most studies were published in English, with two studies published in Portuguese. Regarding methodological design, substantial heterogeneity was

identified: prospective and retrospective cohort studies (n=7)^(22-24,26,31-33), integrative and scoping reviews (n=4)^(9,12,28,34), quasi-experimental studies (n=4)^(25,27,29-30), descriptive studies (n=2)⁽¹⁸⁻¹⁹⁾, a pilot study (n=1)⁽²¹⁾, systematic review with meta-analysis (n=1)⁽²⁰⁾, an experience report (n=1)⁽¹⁰⁾ and an opinion article (n=1)⁽¹⁷⁾. This diversity reflects the fact that the field is still consolidating, highlighting the need for more robust research providing higher levels of evidence.

Figure 2 - Distribution of studies included in the scoping review by year of publication, country of origin, and methodological design. Teresina (PI), Brazil, 2025.



*Number of articles published by country.

Source: Prepared by the authors (2025).

Regarding the target population, 11 studies focused on hospitalized patients in general^(10,12,17,19-20,24,27,30,33-34), seven on patients admitted to Intensive Care Units (ICU)^{(9,21,25-}

^{26,29,31}) and 11 on groups of patients at high risk of developing injuries, such as patients with reduced mobility^(18,22-23,28-34).

The studies analyzed technologies such as wearable sensors^(9,21,25,27,29,32-33), pressure mapping systems^(17,23), air-assisted devices⁽¹⁸⁾, low-pressure mattresses, alternating pressure, automatic repositioning, and monitoring systems^(12,19-20,28,30), fluidized positioning devices⁽²⁶⁾, machine learning^(22,24,26,31), moisture scanners⁽²⁹⁾, injury thermography⁽³¹⁾, deep tissue ultrasound⁽³⁴⁾ and dashboards for protocol monitoring⁽¹⁰⁾.

Research showed that technologies such as wearable sensors and pressure redistribution mattresses significantly reduced the incidence of PI^(9,12,21,27-29,32,34), while fluidized positioning devices and pressure mapping systems demonstrated improvements in injury prevention and healing^(17,23,26). Machine learning models were successful in predicting injury risk, with high accuracy in clinical settings^(22,24,26), and technologies for the early detection of tissue, thermal, and structural changes in the skin enhanced the diagnostic capacity for PI prevention by complementing traditional clinical scales with objective and sensitive methods for the early detection of tissue damage^(29,31,33).

Finally, identified barriers and limitations include the need for further validation across different settings^(24,26,31-32,34), high costs and the need for professional training^(12,21,29-31,33), the need for integration into care workflows and technical standardization^(29,33-34) and challenges in tailoring technologies to specific patient needs^(20,28), as presented in Chart 2.

Chart 2 - Description of articles by authors, technology identification, target population, results, barriers and limitations. Teresina (PI), Brazil, 2025.

Authorship/ Study design/JBI level	Technology identification	Target population	Results	Barriers and limitations
Pompeo <i>et al.</i> ⁽¹⁷⁾ Opinion article/ editorial Level 5	The mapping system, Wellsense Inc., Nashville, Tennessee, is a thin mat placed over a mattress.	Patients with PIs* or those considered at high risk of developing pressure ulcers.	The pressure mapping system demonstrated potential to assist in PI* prevention by providing continuous monitoring of body pressure distribution, which may contribute in the future to changes in care practices and	Although only changes in nursing practice were measured in this study, the observed changes suggest that the technology may be instrumental in reducing hospital-acquired PI* and improving PI* healing in the future.

			improved healing.	
Deter <i>et al.</i> ⁽¹⁸⁾ Retrospective descriptive study Level 4.c	Air-assisted device.	Patients with mobility dependence.	The air-assisted device was associated with a reduction in the incidence of new PI* and improved healing of existing injuries, demonstrating safety during the mobilization of patients with mobility dependence. Continued use of the device did not increase the risk of additional injuries, reinforcing its safety and effectiveness.	The small sample size hindered robust statistical analyses.
Pagnamenta <i>et al.</i> ⁽¹⁹⁾ Quasi-experimental pre-post study Level 2.d	Low-pressure mattresses and alternating systems.	Hospitalized patients.	In a study conducted in a tertiary hospital in the United Kingdom focusing on PI* prevention strategies, the use of low-pressure mattresses and alternating pressure systems was included. The results showed that 98.6% of the surfaces used were non-powered, with a significant reduction in the incidence of hospital-acquired PIs*. Multifaceted strategies, such as skin care, repositioning, and nutrition, complemented the intervention.	The need for frequent audits and training was identified.
Prado <i>et al.</i> ⁽²⁰⁾	Low-air-loss	Hospitalized	The publication	Support surfaces do

Systematic review with meta-analysis Level 1.a	mattresses and alternating pressure systems.	patients in general.	focused on support surface technologies, such as low-air-loss mattresses and alternating pressure systems, which significantly reduced the development of PIs* in hospitals. The study highlighted the importance of tailoring technologies to patients' specific needs and managing other factors such as immobility, nutrition, previous injuries, among others.	not replace patient repositioning; care should be customized.
Barakat-Johnson <i>et al.</i>⁽²¹⁾ Prospective pilot study (quasi-experimental) Level 2.c	Fluidized positioning device (Z-Flo).	127 ICU patients[†] on mechanical ventilation or with elevated intracranial pressure.	The pilot study conducted in Australia evaluated the use of the Z-Flo fluidized positioning device in ICU[†] patients at high risk of occipital injuries. Implementation of the device reduced the incidence of injuries in this region by 87.7%. The results showed that the positioning device provided anatomical support and effective pressure redistribution and was well accepted by the nursing staff because of its ease of use. However, the study	The study was limited to ICU[†] patients on mechanical ventilation or with elevated intracranial pressure.

			highlighted the need for large-scale evaluations to validate the observed benefits.	
Song <i>et al.</i> ⁽²²⁾ Retrospective cohort study (predictive model development) Level 3.e	Machine learning technology.	1,673 patients with PI*	The machine learning-based PI* prediction model could be used as a PI* prevention tool, with broad prospects.	The study was limited to the hospital's electronic medical record database. There was only a strong correlation between the model's inference and the characteristics, but establishing a complete causal relationship remains impractical.
Zimlichman <i>et al.</i> ⁽²³⁾ Prospective cohort study Level 3.c	Bed movement and activity monitor – EverOn.	116 hospitalized patients.	The high correlation between the EverOn system's movement score and the calculated Norton Scale score indicated the potential of this technology as a risk assessment tool for PI* development.	Assisted patient repositioning was not documented when bed movement was recorded.
Nakagami <i>et al.</i> ⁽²⁴⁾ Retrospective observational cohort study Level 3.e	Machine learning models (XGBoost, Random Forest).	75,353 hospital records of hospitalized patients.	This retrospective cohort study conducted in Japan used data from 75,353 hospital records to develop a predictive model using machine learning. The XGBoost model achieved an AUC [‡] of 0.80 ± 0.02 , highlighting risk factors such as difficulties with activities of daily living and respiratory disorders. The	A need for further validation in different settings was identified.

			study reinforced the value of using routinely collected electronic records to predict injuries during hospitalization.	
Oh <i>et al.</i>⁽²⁵⁾ Prospective pilot study (technology validation) Level 2.c	Wireless, battery-free sensors.	Patients at risk of injury.	The study introduced wireless, battery-free sensors that continuously monitored skin pressure and temperature at multiple body sites. The technology was tested in patients with hemiplegia and tetraplegia, demonstrating feasibility, functionality, and long-term stability in a hospital setting. The sensors provided accurate readings without interference from shear forces, making them useful for the early detection and management of PI*.	The need for further validation with larger samples was noted.
Xu <i>et al.</i>⁽²⁶⁾ Retrospective cohort study (model development and validation) Level 3.e	High-performance clinical feature panel accessible through electronic medical records.	412 ICU patients [†]	A combined approach using the Braden Scale and a machine learning-based clinical model was validated as beneficial for PI* prevention in the ICU[†].	Extrapolating the model to other medical institutions was found to be difficult. Furthermore, a sequential prospective cohort study to test the model in a real-world setting would provide compelling evidence for the predictive model.
Turmell <i>et al.</i>⁽²⁷⁾	Wearable sensors.	29 ICU patients [†]	The study analyzed wearable sensors that provided visual	Cost and the need for training were identified as

Quasi-experimental study (pre-post implementation) Level 2.d			alerts for patient repositioning in the ICU[†]. In a 12-bed unit, adherence to the two-hour repositioning protocol increased from 55% to 89% after the introduction of the sensors, reducing the mean repositioning interval from 3.8 hours to 2.3 hours. Improvements were observed in PI* prevention and staff perceptions of teamwork.	barriers.
Youn <i>et al.</i>⁽²⁸⁾ Scoping review Level 1.b	Mattresses, dressings, electrical stimulation.	Patients at high risk of injury.	A review of 13 clinical studies on devices for PI* prevention and treatment included mattresses, specialized dressings, and electrical stimulation. The devices demonstrated effectiveness in reducing the incidence of injuries and improving patients' quality of life. The review highlighted the need for studies with larger samples to validate the findings.	Larger-scale studies are required for validation.
Crotty <i>et al.</i>⁽⁹⁾ Integrative review Level 1.b	Wearable sensors.	Hospitalized patients.	Wearable sensors contributed to greater adherence to repositioning protocols, in addition to reducing hospital-acquired	This technology has been most frequently studied in ICU. [†] Future research focusing on different patient populations is

			PI* and healthcare costs.	needed to determine efficacy outside the ICU. †
Araújo <i>et al.</i>⁽¹²⁾ Integrative review Level 1.b	Mattresses and moisture sensors.	Hospitalized patients.	The review identified technologies such as pressure redistribution mattresses, moisture sensors, and continuous monitoring devices. The implementation of these technologies in Brazilian hospitals was associated with a significant reduction in PI* incidence, but challenges related to costs and professional training for proper handling were highlighted.	High costs and the need for professional training were observed.
Fini <i>et al.</i>⁽¹⁰⁾ Methodological study/technological development Level 4.c	Dashboard.	Patients at risk of and/or with skin injuries and ostomies.	The development and implementation of the dashboard for managing the PI* protocol enabled rapid, real-time visualization of patients' risks.	The results are sensitive to the context studied and therefore cannot be generalized, but they may be extrapolated to other institutions with similar settings.
Bayoumi <i>et al.</i>⁽²⁹⁾ Longitudinal comparative descriptive study Level 3.c	Subepidermal moisture (SEM) scanner for early detection of deep tissue damage.	189 critically ill, immobilized patients in the ICU [†] .	The subepidermal moisture scanner enabled the early detection of deep tissue damage, identifying the risk of PI* approximately three days before visible clinical manifestations. Sensitivity was 89.2% versus 48.6% for the	The need for staff training was identified. The technology is complementary and does not replace clinical assessment. An institutional protocol is required.

			Modified Cubbin and Jackson (MCJ) Scale.	
Taryudi <i>et al.</i> ⁽³⁰⁾ Prospective quasi-experimental Level 2.c	IoT ^δ -enabled smart bed - automatic repositioning + physiological monitoring.	30 patients hospitalized for stroke ^l .	The IoT ^δ enabled smart bed with automatic repositioning improved risk factors assessed by the Braden Scale and reduced the workload of the care team.	High technological costs and the need for hospital infrastructure to incorporate the technology were reported. The sample was small (n = 30).
Burke <i>et al.</i> ⁽³¹⁾ Retrospective observational study Level 3.e	Thermographic imaging for the early detection of PI.*	Critically ill patients in a surgical ICU [†] .	Better prediction was observed compared with the Braden Scale. Early identification of deep injuries was achieved. Potential reductions in costs and complications were observed.	Better prediction was observed compared with the Braden Scale. Early identification of deep injuries was achieved. Potential reductions in costs and complications were observed.
Smith; Steckler. ⁽³²⁾ Prospective cohort study Level 3.d	Mattress-attachable wireless motion sensor for continuous monitoring of movement.	Hospitalized patients at risk of PI.*	The wireless motion sensor enabled continuous monitoring of in-bed movements, identifying prolonged periods of immobility and patients at higher risk of PI*. A strong correlation with video analysis was observed (r = 0.89). The mean was 9.7 movements/hour. Immobility alerts identified patients at higher risk. Objective mobility data were obtained, surpassing subjective assessments. The technology demonstrated potential for PI* prevention.	The need for broader clinical validation, integration into the care workflow, and the fact that the technology has not yet been widely implemented were identified.

Ren Q <i>et al.</i> ⁽³³⁾ Prospective diagnostic study Level 2.b	Deep tissue ultrasound assessment for PI* prediction.	Hospitalized patients at risk of PI.*	Early prediction of hospital-acquired injuries was demonstrated. AUC [‡] = 0.898, higher than that of the Braden, Norton, and Waterlow scales. Sensitivity was 0.884 and specificity was 0.781. This is a promising method for the early identification of tissue damage.	The need for technical standardization, dependence on trained operators, and limitations in the dissemination of the technology were identified.
Angelucci <i>et al.</i> ⁽³⁴⁾ Scoping review Level 1.b	Wearable devices for continuous physiological monitoring.	Hospitalized critically ill patients, especially those in ICU. [†]	Continuous, noninvasive monitoring of physiological parameters and mobility showed potential for the early detection of clinical deterioration, increased adherence to repositioning, and PI* prevention in critically ill patients.	Variable measurement accuracy, signal loss and motion artifacts, connectivity and integration limitations with clinical systems, the need for validation in real-world settings, and the risk of data overload were observed.

*PI = Pressure Injury; [†]ICU = Intensive Care Unit; [‡]AUC = Area Under the Curve; [§]IoT = Area Under the Curve; ^{||}CVA = Cerebrovascular Accident
Source: Prepared by the authors (2025).

To facilitate the comparative visualization of the identified technologies, Chart 3 presents an organizational synthesis of the technologies by category, mechanism of action, clinical context of application, and JBI level of evidence.

Chart 3 - Synthesis of hard technologies for PI prevention by category, mechanism of action, clinical context, and level of evidence. Teresina (PI), Brazil, 2025.

Category	Technology	Mechanism of action	Clinical context	JBI Level	Studies (n)
Pressure and position monitoring	Wearable and wireless sensors	Continuous monitoring of pressure and skin temperature; repositioning	ICU* / Ward	1b - 2c/d	6

Category	Technology	Mechanism of action	Clinical context	JB1 Level	Studies (n)
		alerts.			
Pressure and position monitoring	Pressure mapping systems	Sensor mat that maps pressure distribution over the mattress in real time.	General	4c - 5	2
Pressure and position monitoring	Bed-mounted mobility sensor	Continuous monitoring of movement; immobility alerts.	General	3d	1
Support surfaces	Low-pressure mattresses and alternating systems	Pressure redistribution and alternation beneath the patient's body.	General/ ICU*	1a - 2d	3
Support surfaces	Fluidized positioning device (Z-Flo)	Pressure redistribution in the occipital region using fluidized material.	ICU*	2c	1
Support surfaces	Air-assisted device	Reduction of friction and shear during mobilization.	General	4c	1
Artificial intelligence prediction	Machine learning (ML [‡]) models	Predictive algorithms (XGBoost, Random Forest) integrated into electronic medical records for risk stratification.	ICU* / General	1b - 3e	3
Early detection of tissue damage	Subepidermal moisture (SEM) scanner	Biocapacitance to detect subepidermal edema preceding PI. [†]	ICU*	3c	1
Early detection of tissue damage	Infrared thermography	Identification of skin temperature changes before clinical manifestation of PI. [†]	Surgical ICU*	3e	1
Early detection of tissue damage	Deep tissue ultrasonography	Structural assessment of subcutaneous tissue for early PI prediction. [†]	General	2b	1
Protocol management	Computerized dashboard	Real-time visualization of patient risk and adherence to the preventive protocol.	General	4c	1
Protocol management	IoT-enabled smart bed. [§]	Automatic repositioning and integrated physiological monitoring.	General	2c	1

*ICU: Intensive Care Unit; [†]PI: Pressure Injury; [‡]ML: Machine Learning; [§]IoT: Internet of Things; JBI: Levels of evidence according to the JBI hierarchy for effectiveness⁽¹⁶⁾.

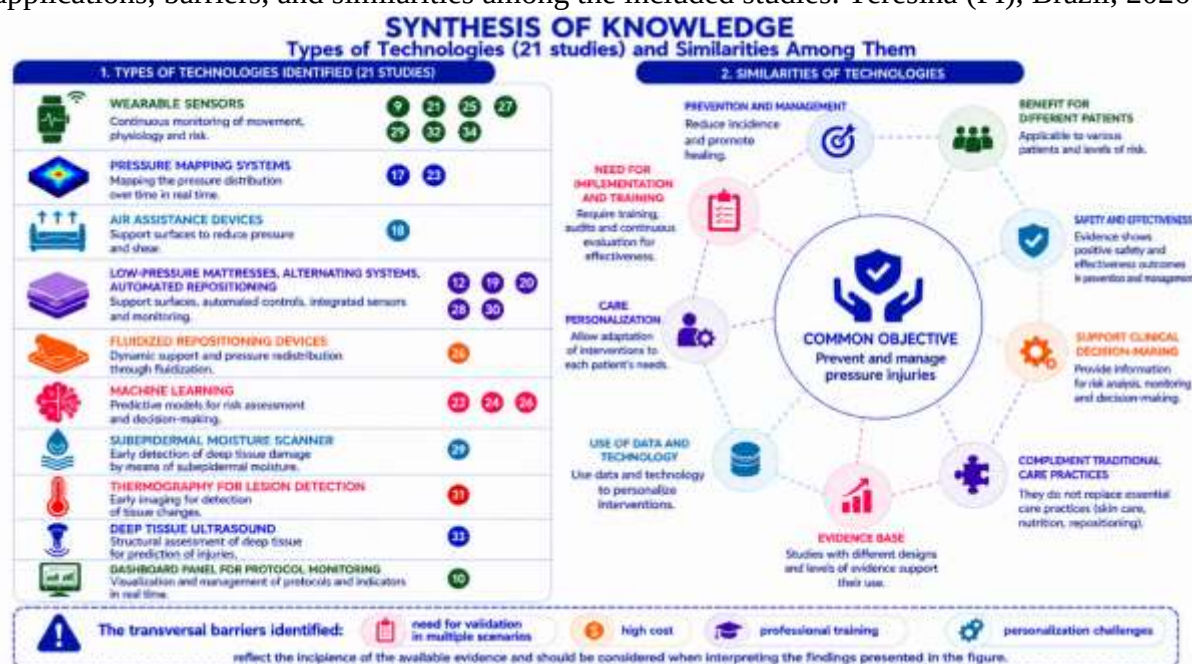
Source: Prepared by the authors (2025).

The final sample of 21 studies showed heterogeneity in levels of evidence: one Level 1.a study (systematic review with meta-analysis)⁽²⁰⁾, our Level 1.b studies (integrative and scoping reviews)^(9,12,28,34), six Level 2 studies (prospective pilot and quasi-experimental studies)^(19,21,25,27,30,32), seven Level 3 studies (prospective and retrospective cohort studies)^(22-24,26,29,31,33), two Level 4 studies (descriptive and methodological studies)^(10,18) and one Level 5

study (opinion article)⁽¹⁷⁾. This diversity reflected the exploratory nature of the field, with a predominance of observational studies (59%) and literature reviews (27.2%), indicating an early stage in the development of evidence on technologies for PI prevention.

Figure 3 presents, in graphic format, the main technologies identified in the included studies, organized by category and type of application. The numbers in each category correspond to the bibliographic references of the studies included in this scoping review. Despite the heterogeneity of the interventions, the studies demonstrated important similarities regarding the objectives of the technologies, particularly PI prevention, reduction of complications, personalization of care, support for clinical decision-making, and improvement of patient safety.

Figure 3 – Synthesis of knowledge on technologies for PI prevention and management: types, applications, barriers, and similarities among the included studies. Teresina (PI), Brazil, 2026.



* The numbers in each category correspond to the bibliographic references of the studies included in this scoping review.

Source: Prepared by the authors (2026), using the ChatGPT tool (OpenAI, version 5.0).

DISCUSSION

Analysis of the results obtained allowed the mapping of a set of hard technologies aimed at PI prevention in hospitalized patients, revealing relevant contributions to patient safety and quality of care. The most recent international guidelines reinforce that the use of technologies should be integrated with traditional measures, such as risk assessment, regular

repositioning, and appropriate use of support surfaces, corroborating the relevance of the findings of this review⁽³⁴⁾.

Six studies highlighted the use of wearable and wireless sensors as a promising strategy for PI prevention, particularly in ICUs, where these devices increased adherence to repositioning protocols and reduced the interval between preventive actions^(9,25,27,29,32,34). One of the models evaluated provides a visual alert to signal the need for repositioning, resulting in an increase in staff adherence from 55% to 89%⁽²⁷⁾. Wireless devices capable of monitoring skin pressure and temperature demonstrated good stability and feasibility in the hospital setting⁽²⁵⁾, while bed sensors with continuous movement monitoring showed a strong correlation with video analysis ($r=0.89$), outperforming subjective assessments of mobility⁽³¹⁾. Wearable sensors also contributed to reducing the incidence of injuries, and validation in larger populations is essential to expand their application across different clinical settings^(9,34).

The efficacy of sensors with pressure and temperature monitoring in the early prediction of risk factors, facilitating targeted interventions and reducing complications, is supported by a recent integrative review⁽⁹⁾. Future research should prioritize validation in non-critical populations, implementation studies in different settings, and cost-effectiveness analyses, particularly in low- and middle-income countries, where the initial cost of sensors may be prohibitive^(9,32,34). The smart mat for monitoring body positions represents a complementary innovation with potential to optimize resource allocation and improve patient safety provided accompanied by ongoing staff training⁽³⁵⁾.

A meta-analysis involving 19,136 patients demonstrated a 70% reduction in the incidence of injuries with the use of wearable sensors, with estimated annual savings of US\$6.2 million per 1,000 patients, considering avoided treatment costs⁽³⁶⁾. Three critical issues emerge from this evidence: first, the limited validation in intensive care settings represents an important gap, since patients in general wards have distinct risk profiles and less availability of continuous monitoring; second, none of the studies in this review assessed the sustainability of long-term adherence. “Alarm fatigue,” a phenomenon characterized by a progressive reduction in healthcare professionals’ responses to repetitive clinical alarms, documented in settings involving intensive electronic monitoring⁽³⁷⁾, may compromise effectiveness after the initial implementation period; third, the available cost-effectiveness analyses are based on high-income healthcare systems, with limited transferability to resource-constrained settings.

International guidelines reinforce that systematic repositioning measures should guide prevention programs, with individualized frequency according to clinical assessment, in

addition to the use of reminder strategies to promote adherence⁽³⁴⁾. These recommendations support the use of sensors and alert systems as aids to repositioning practices, without replacing clinical judgment⁽³⁶⁾. Ethical issues related to the privacy of continuous biometric data and patient acceptability of these technologies remain unexplored in the included studies and represent a priority agenda for future research.

Regarding therapeutic mattresses and pressure-redistribution devices, their efficacy was widely recognized in the studies evaluated. Research conducted in UK hospitals indicated that low-pressure mattresses and alternating-pressure systems significantly reduced the incidence of injuries in hospital settings⁽¹⁹⁾. International consensus strongly recommends the use of pressure redistribution support surfaces for individuals at risk, guiding the selection between active and reactive surfaces according to the patient's clinical condition and mobility, and emphasizing that the absence of such surfaces represents a high risk of tissue damage⁽³⁸⁾. Low-air-loss mattresses and alternating pressure systems significantly reduced the development of pressure injuries in hospitals, making it essential to tailor these technologies to the patient's clinical profile⁽²⁰⁾.

The Z-Flo fluidized positioning device, evaluated in ICU patients, demonstrated an 87.7% reduction in occipital injuries, reinforcing its effectiveness as a practical solution for pressure redistribution in high-risk populations⁽²¹⁾. A scoping review corroborates the effectiveness of combined devices, such as mattresses, specialized dressings, and electrical stimulation, in preventing pressure injuries and improving patient quality of life, highlighting the need for studies with larger samples to validate the findings⁽²⁸⁾. Proper use of pressure-redistribution mattresses, compared to standard hospital mattresses, combined with regular repositioning, significantly reduces the risk of PI⁽³⁹⁻⁴⁰⁾.

Continuous movement monitoring technologies demonstrated effectiveness in identifying behavioral patterns associated with PI risk. The EverOn system showed a high correlation with the Norton Scale, enabling early interventions, although the lack of documentation of assisted patient repositioning was identified as a limitation to its broader applicability^(23,32). The consensus of the National Pressure Injury Advisory Panel (NPIAP) emphasizes the importance of repositioning to optimize pressure redistribution and offload bony prominences⁽³⁸⁾, reinforcing the value of technologies that facilitate or automate this practice in reducing PI risk.

Machine learning-based predictive models stood out for their high accuracy in predicting pressure injuries. The *Random Forest* model achieved an area under the curve greater than 0.95, demonstrating greater accuracy compared with traditional methods⁽²²⁾. The

XGBoost model was validated with an AUC of 0.80 ± 0.02 , identifying difficulties with activities of daily living and respiratory disorders as important predictors⁽²⁴⁾. The integration of machine learning algorithms with the Braden Scale resulted in a significant improvement in the early identification of risk factors in ICU patients⁽²⁶⁾.

The computerized dashboard for managing the Pressure Injury Prevention Protocol enabled real-time visualization of patients' risks, promoting improved adherence to preventive practices⁽¹⁰⁾. Although there are still no specific recommendations regarding artificial intelligence or predictive models in international guidelines, the relevance of clinical decision support systems and reminder strategies to optimize adherence to preventive practices is already recognized⁽³⁸⁾. The digital technologies analyzed should be understood as complementary operational supports to the core measures established in the guidelines.

Early diagnostic technologies demonstrated high predictive performance. The subepidermal moisture scanner demonstrated a sensitivity of 89.2%, higher than that of the Modified Cubbin and Jackson Scale (48.6%), enabling risk identification up to three days before clinical manifestations⁽²⁹⁾. Deep tissue ultrasound assessment showed an AUC of 0.898, with a sensitivity of 0.884 and specificity of 0.781, outperforming the Braden, Norton, and Waterlow scales in risk stratification among critically ill patients⁽³²⁾. Infrared thermography also proved useful for the early detection of deep tissue injuries, offering better predictive capability than the Braden Scale and indicating that thermal changes may precede visible clinical signs⁽³¹⁾.

The mapped technologies have the potential to transform preventive care in hospital settings, especially when integrated with traditional practices, constituting a complementary approach capable of maximizing benefits and promoting greater patient safety. Relevant challenges, such as the need for validation in different contexts and populations, high costs, adequate infrastructure, and continuous staff training, restrict universal access to innovations and reinforce the urgency of future research aimed at technological integration and the improvement of care practices^(12,21,29-30,33).

This study presents methodological limitations that should be considered when interpreting the findings. The search limited to Brazilian repositories of gray literature may have excluded relevant international theses and dissertations. The exclusion of technology-specific databases (IEEE Xplore, ACM Digital Library) represents a potential gap regarding innovations in the development phase. The data extraction did not systematically capture information on implementation feasibility, patient acceptability, and organizational sustainability, which are critical factors for translating technologies into practice. Finally, the

heterogeneity of outcomes precluded quantitative synthesis, limiting the objectivity of the conclusions.

This study contributes to clinical practice by providing a comprehensive overview of available hard technologies for the prevention of PI in hospitalized patients, enabling managers and clinicians to understand the scope of existing innovations. The contributions focus on mapping the state of the art in technology; identifying gaps for future research, particularly regarding external validation, cost-effectiveness analyses for low- and middle-income countries, and implementation studies in non-intensive care settings; highlighting consistently reported barriers, such as costs, training, and personalization; and supporting the formulation of research questions for systematic reviews with rigorous quality assessment.

Based on the identified gaps, the following are suggested: implementation studies assessing barriers and facilitators in different contexts; cost-effectiveness analyses comparing emerging technologies versus standard care; external validation of predictive models in multicenter cohorts; qualitative studies on the acceptability of technologies among patients and healthcare professionals; and pragmatic clinical trials comparing different technologies under real-world conditions. Implementation decisions should be based on complementary systematic reviews with critical appraisal of the evidence.

FINAL CONSIDERATIONS

This scoping review mapped hard technologies used in the prevention of PIs among hospitalized adult and older adult patients, identifying five categories: pressure and position monitoring; support surfaces; artificial intelligence-based prediction; early detection of tissue damage; and integrated protocol management. The studies analyzed demonstrated that wearable and wireless sensors improved adherence to repositioning, machine learning-based predictive models showed satisfactory performance for risk stratification, and early detection technologies enabled the identification of tissue changes before their visible clinical manifestation.

Overall, the mapped technologies showed potential to improve PI prevention by expanding the capacity for continuous monitoring, early detection, and objective risk identification. However, the available evidence was predominantly concentrated in high-complexity hospital settings, particularly ICU, with a predominance of studies conducted in high-income countries.

Gaps remain, including the external validation of technologies in non-intensive care settings and in low- and middle-income countries, cost-effectiveness analyses compared with

standard care, implementation studies in different care settings, and pragmatic clinical trials under real-world conditions. Generating evidence in these areas is essential for the equitable and sustainable incorporation of these innovations into clinical practice.

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Data and material availability

Access to the dataset is available upon request from the corresponding author.

Authorship contribution

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Conflict of interest

The authors declare that there is no conflict of interest.

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