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Advances in technology-driven strategies for preventing and managing bedsores: A comprehensive review

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A R T I C L E I N F O

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A B S T R A C T

Bedsores, commonly known as pressure ulcers, are a major healthcare issue with far-reaching effects on patient welfare and the healthcare system. This review provides an extensive summary of the existing body of knowledge on the management and prevention of bedsores. Traditional approaches for preventing bedsores include regular repositioning, nutritional assessments, the use of pressure-relief devices, and wound care protocols. Despite these approaches, the incidence of bedsores remains a challenge, and there is a need for further studies on customized pressure redistribution products and their impact on sleep quality. Technology-based prevention strategies for bedsores include the use of pressure-relieving support surfaces, such as smart mattresses and cushions, to monitor pressure, temperature, and humidity, allowing for adjustable firmness and contour redistribute pressure. Wearable sensors continuously monitor the pressure points, and pressure mapping systems assess the pressure distribution between the body and surface, providing real-time feedback. Telemedicine platforms and mobile apps for self-monitoring can also be employed to monitor patients remotely, assess skin conditions, and provide guidance for prevention and care. Clinical evidence assessing the effectiveness of various preventive tools and interventions suggests that they can improve patient outcomes and reduce the incidence of bedsores. It also outlines the complexities and limitations associated with managing pressure ulcers. The review explores several preventive techniques which highlights the economic and social burden of pressure ulcers

Introduction

Bedsores, also known as pressure or decubitus ulcers, are a prevalent and costly concern in the healthcare domain. Millions of patients globally, particularly those with limited mobility, are susceptible to the development of debilitating wounds. Prolonged pressure on specific body areas restricts blood flow, leading to tissue damage, pain, and an increased risk of infection. (Gefen, 2017; National Pressure Ulcer Advisory Panel 2014) Beyond the direct impact on patients, pressure ulcers impose a significant financial burden on healthcare systems due to the extended hospital stays and specialized care required for their treatment. (Maklebust, 2011)

This critical issue necessitates exploration of effective preventive measures. Traditional methods such as patient repositioning and pressure-relieving support surfaces remain the cornerstone of pressure ulcer prevention. However, this review focuses on the rapidly evolving field of technology-driven solutions to prevent and manage pressure ulcers. These innovative approaches offer the potential to augment existing strategies, enhance patient outcomes, and mitigate healthcare costs associated with pressure ulcers.

The impact of bedsores: a growing concern

Pressure ulcers, also referred to as bedsores, are a serious health care problem that has a significant impact on both patients and the health care system. People who are bedridden, confined to wheelchairs, or have limited mobility frequently develop wounds as a result of prolonged pressure on specific body parts (Gefen, 2017; Maklebust, 2011). The

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development of bedsores is also associated with significant physical and emotional consequences that affect patients' overall well-being and quality of life (Spilsbury, Nelson, & Cullum, 2007).

Physically, bedsores cause pain, discomfort, and reduced mobility in the affected individuals. Patients experience discomfort and distress due to constant pressure on localized areas, which can lead to inflammation and tissue damage (Reddy et al., 2006). Constant pressure restricts blood flow to the affected regions, depriving the tissues of vital nutrients and oxygen and leading to tissue breakdown. As the condition worsens, the wounds can deepen, affecting the muscle and bone and causing severe pain in patients (Dealey & Brindle, 2012; Kottner, Wilborn, Dassen, & &Halfens, 2010; Milne, Trigilia, & Paul, 2016).

Moreover, untreated bedsores can lead to severe complications, particularly in immunocompromised and elderly individuals. The weakened immune system of these individuals makes them more susceptible to infections. Bedsores provide an entry point for bacteria, increasing the risk of infections, such as cellulitis and sepsis (Mirasoglu & Yildiz, 2019). In severe cases, these infections can be life threatening and require aggressive medical interventions.

Beyond their direct impact on patients, bedsores pose a significant economic burden on the healthcare system. The cost of treating advanced pressure ulcers is far greater than the expense incurred for their prevention. Hospitalizations for severe bedsores lead to longer stays, increased utilization of healthcare resources, and the need for specialized wound care. These treatments are costly and require skilled healthcare professionals and dedicated wound care teams, which adds to the financial strain on healthcare institutions. Moreover, the economic implications extend beyond the hospital setting, affecting long-term care facilities and community-based healthcare providers who bear the responsibility of managing and treating bedsores in patients discharged from hospitals (Jefferson, Slocombe, & Kilbride, 2018).

The purpose of this literature review is to explore the role of technology-driven solutions in preventing bedsores. We aimed to discuss innovative approaches that complement traditional prevention methods and improve patient outcomes, while reducing healthcare costs.

Traditional approach for prevention of bedsores

Given the grave consequences of bedsores, healthcare providers have traditionally relied on the repositioning of patients, nutritional assessment, pressure relief devices, and wound care protocols as the primary approaches to bedsores prevention

Repositioning: Regular repositioning of patients is a common preventive measure to reduce the pressure on vulnerable areas. Healthcare providers frequently turn bedridden patients every two hours to distribute pressure evenly across different body parts. However, this approach has limitations, as it requires significant human resources and patient compliance may vary (Kaddoura & Abu-Shaheen, 2019).

Nutritional Assessment: Malnutrition increases the risk of pressure ulcer. Optimal nutrition supports the immune function, collagen formation, and skin strength. Indicators such as weight loss, serum albumin level, and lymphocyte count can help identify malnutrition. A comprehensive nutritional assessment is critical for prevention and healing (Posthauer, Banks, Dorner, & Schols, 2015)

Pressure Relief Devices: Specialized pressure relief mattresses, cushions, and overlays are used to reduce the pressure on the bony prominences and vulnerable areas. These devices are designed to evenly distribute the patient's weight and alleviate pressure on specific regions. Although effective, the success of these devices depends on their proper selection, positioning, and ongoing assessment, which can be resource intensive (Reddy et al., 2006).

Wound Care Protocols: Wound care protocols are essential for managing existing bedsores and preventing their progression. They involve regular cleaning, debridement, and dressing changes to promote wound healing and prevent infection. However, these protocols do not address the root cause of bedsores, making proactive prevention critical (Baranoski & &Ayello, 2016; Santamaria & &Gerdtz, 2018).

Despite the availability of training and resources, the incidence of pressure ulcers has slightly reduced. Despite advancements in wound care techniques and dressings, the best strategy is not yet widely accepted (Reddy et al., 2006).

Technology-driven strategies are emerging as valuable complements to traditional methods with the aim of addressing some of their limitations. Smart surfaces and wearables use real-time data to automatically adjust pressure or alert caregivers, whereas mobile applications empower patients and staff with reminders, education, and self-management tools. This proactive approach improves compliance and effectiveness compared to traditional methods.

Although traditional approaches remain essential, technology-driven solutions offer significant advantages.

- **Automating tasks:** Reducing the need for manual repositioning and monitoring, freeing up caregiver time.
- **Providing real-time data:** Enabling proactive interventions and personalized care plans.
- **Improving patient compliance:** Offering automated reminders and promoting self-management.
- **Enhancing cost efficiency:** Potentially reducing hospital stays and treatment costs associated with advanced pressure ulcers.

Technology-Based Prevention Strategies

Technology-based solutions to prevent bedsores can improve patient care and reduce the incidence of painful and potentially fatal lesions. These strategies can be applied in a wide range of fields, including health care. Technology-based solutions to prevent bedsores can improve patient care and reduce the incidence of painful and potentially fatal lesions.

Pressure-relieving support Surfaces

Several types of pressure-relieving support surfaces are available, such as variable pressure mattresses, water beds, air fluidized beds, lateral rotation beds, and low-air loss beds, which are used to prevent pressure ulcer formation (Hultin, Olsson, Carli, & Gunningberg, 2017). Based on two ideas, smart mattress and cushions, an effort is made to relieve pressure on a bony protrusion, and it is possible to either expand the area in contact with the support surface or temporarily remove or shift contact to other places.

Smart Mattresses and Cushions: Smart mattresses and cushions are equipped with sensors that monitor pressure, temperature, and humidity. These devices are versatile, convenient, and portable support surfaces that can adjust the firmness and contour of the surface to redistribute pressure and reduce the risk of bedsores. They can also provide regular position changes to alleviate pressure on vulnerable areas and can fix problems with water mattresses, such as heaviness due to the presence of additional water difficulties shifting the water bed and non-suitability for other applications, such as wheelchair cushions. Different types of cushion models (Lee et al., 2023) are available, as listed in Table 1.

The cushions have a cover on top of them, which serves as protection, with an exterior layer that is breathable and elastic and a non-slip inner layer. The wheelchair arrangement was standardized such that all patients were seated with their feet on footrests, hips, knees, and ankles flexed at 90 ° (Kosmopoulos & Tzevelekou, 2007). Although a tilt of up to 10 °was permitted to improve patient comfort, the seat was parallel to the ground and the back was perpendicular. It is highly helpful to evaluate the mechanical properties of various types of cushions using a user-cushion interface pressure-recording system. Regarding the pressure distribution, it was found that the dual-compartment air cushion had the best mechanical performance and contact surface at the user-cushion interface compared to the other three cushions studied

Table 1
Comparison of different cushions types.

Cushion	Type	Description	Manufacturer
Cushion 1	Single-compartment	low-profile air cushion	Kineris low-profile model, AskleSantéWinncare (AskleSantéWinncare Group, Nimes, France).
Cushion 2	Single-compartment	high-profile air cushion.	Kineris high-profile model, AskleSantéWinncare (AskleSantéWinncare Group, Nimes, France)
Cushion 3	Dual-compartment air cushion	It is divided into two chambers that simulate an ergonomic seating base.	Roho Enhancer Model, The Roho Group (Roho, Inc., Belleville, IL, USA).
Cushion 4	Cushion	Gel and firm foam cushion	Medical Sunrise Jay-2 Model (Jay Medical, Ltd., Boulder, CO, USA).

(low-profile air, high-profile air, and gel and firm foam). People who use wheelchairs often use cushions to distribute pressure more evenly in the support region and lower their risk of developing pressure ulcers. Comparative studies of cushions have measured outcomes based on the appearance of the first skin lesion (Engelen, van Dulmen, Vermeulen, de Laat, & van Gaal, 2021; Sundar, Das, & Deshmukh, 2015). However, such investigations require large patient samples and months of continuous skin health monitoring.

Smart Air Mattress: The Smart Air Mattress detects pressure points while changing positions and sleeping patterns. The device is specifically designed to prevent the patient's muscles from sustained fixed pressure at the same position as bedsores (Qidwai, Al-Sulaiti, Ahmed, Hegazy, & Ilyas, 2016).

A. F*orce-sensing resistors (FSRs)* are durable polymer thick-film devices that exhibit a change in their electrical resistance when a force is applied to the surface, and they offer the best results for various patients with various body weights. It is thin compared to other pressure sensors and available in the market that offers a flat mattress surface so that patients can rest comfortably due to the sensor. The FSR was placed on an air mattress surface that was then covered with a thin foam layer. This allows the user to sleep comfortably without sensing the presence of FSR. When a person is sleeping on a mattress, the FSR is activated, and as pressure is applied, its resistance value decreases, causing the Arduino board to turn on or off the relay module. The resistance of the FSR is very high (on the order of hundreds of MΩ) when no force is applied to the FSR. However, when force is applied, the resistance is significantly reduced (Yousefi et al., 2011). FSR is a useful sensor element for biomedical applications where force measurement is required because of its anomalous qualities, which include the need for a small surface area for activation, low cost, versatility, and high endurance to chemicals, moisture, and temperature.

There are different types of sensors used in smart air mattress

- Inertial sensors: Inertial sensors consist of a triaxial accelerometer (3D acceleration), gyroscope (3D angular velocity and orientation), and magnetometer (compass direction), which together can detect motion and determine body trunk angles. Sensors without a warning system employ a sophisticated algorithm to assess body positions rather than the turn angle. (Cicceri, De Vita, Bruneo, Merlino, & Puliafito, 2020; Kwasnicki et al., 2018; Monroy, Rodríguez, Estevez, & Quero, 2020; Zhang and Yang, 2015)
- Piezoresistive sensors: Piezoresistive sensors detect changes in electrical resistance related to the applied force and convert them to pressure measurements (in mmHg). These sensors are frequently placed on top of the mattress below the bedsheet to obtain the most direct pressure-distribution measurements. Piezoresistive sensors are adaptable because their quantity and placement can be modified to suit the application. (Ahmad, Andersson, & Siden, 2018)
- Capacitive sensors: Capacitive sensors are located on the mattress and may detect changes in the electrical charge, allowing pressure measurement or touch detection. (Fryer, Caggiari, Major, Bader, & Worsley, 2023; Matthies, Haescher, Chodan, & Bieber, 2021; Rus, Grosse-Puppendahl, & Kuijper, 2017)
- Load sensors: Load sensors are widely used in bedframes or as pads beneath the bed wheels to detect the weight (distribution) of a person in the bed. By combining the outputs from the load sensors, variations in the center of mass during movement can be estimated and utilized to predict a patient's orientation. (Minteer et al., 2020; Wong et al., 2020)

A. *Valve Regulation*: To manage the airflow inside the mattress, the air channel solenoid air valves are electrically energized or de-energized.
B. *4-channel relay module*: Using voltage and/or current, the relay module permits switching (on or off) the flow of air into the air channels
C. *Air Compressor:* In an air compressor, atmospheric air is drawn in, its volume decreases, and its pressure increases. Pressurized air was then stored in a storage tank. The pressure setting in this is at 0.8 MPa as the air pressure required for air to pass through the orifice of the solenoid air valve is approximately 0.8 MPa.

Wearable sensors

Wearable sensors, such as pressure-sensitive patches or devices, can be placed on a patient's body to monitor pressure points continuously. (Angelova & Sofronova, 2021) These sensors can send alerts to caregivers or healthcare professionals when pressure levels become a concern, prompting them to reposition patients and implement other preventive measures.

To monitor a patient's posture, an effective solution has been presented using force-sensitive sensor strips placed under the patient on a bed in specific pressure zones, and a smart camera embedded with image processing (Buckle, 1998). By using both image processing and force sensors, an accurate account of the patient's position can be maintained continuously, and the duration of inactivity can be determined. Because the number of sensors was kept as low as possible by design, innovative image-processing algorithms were developed to enhance the accuracy of determining whether a patient moved (Kandha Vadivu, 2015). For this purpose, only 25 sensors were used, along with a smart camera (web camera and laptop coupled exclusively for image-processing tasks).

The sensors must be precisely calibrated to detect the movement of the patient in bed, moving arms and legs, turning from one position to another, and raising and lowering the head. In this manner, the sensor registers movement, and it is possible to monitor the duration of immobility of the patient in bed through the data collection system. The system then sends a signal to the person taking care of the patient, as this mobile application is the most convenient method (Brienza et al., 2010). Thus, it is possible to monitor with certainty whether there is a patient's immobilization for some time and to take measures to change the position of the person (to sit in a chair or turn in the bed).The information system can be set for longer time intervals at night so as not to interrupt the patient's sleep, but during the day, to signal every hour or at a time set by the patient caregiver, informing them whether there is immobilization of the body in bed and in which area exactly.

Pressure mapping systems

These systems use sensors and electronic devices to assess the pressure distribution between the body and surface of a mattress or chair. These systems can provide real-time feedback to caregivers and patients, alerting them when there is excessive pressure on specific areas of the body (Brubaker & Sprigle, 1990). The risk of bedsores can be reduced by adjusting the patient's position or providing additional support.

Behrendt et al. reported the frequency of hospital-acquired pressure ulcers (HAPUs) in medical intensive care units to have decreased when nurses had access to pressure mapping equipment. (Behrendt, Ghaznavi, Mahan, Craft, & Siddiqui, 2014) Gunningberg et al. reported pressure mapping equipment in geriatric ward could be used to alert personnel of the need for repositioning and facilitate repositioning as personnel are provided with feedback on pressure points. (Gunningberg, Bååth and Sving, 2018)

Surgical patients are considered vulnerable and at high risk of developing HAPUs. Operating room teams need to tailor their pressure ulcer prevention plans according to each patient's individual needs. Having access to information on body locations with high-pressure points could be one way of strengthening prevention work during surgery. Results from a feasibility study showed that using pressure-mapping equipment is possible in the operating room. (Sving, Bååth, Gunningberg, & Björn, 2020)

Telemedicine and remote monitoring

Telemedicine platforms enable healthcare professionals to remotely monitor patient conditions. (National Pressure Ulcer Advisory Panel 1991) For individuals at risk of bedsore development, healthcare providers can use video consultations and image sharing to assess a patient's skin condition and recommend appropriate interventions.

Mobile apps for self-monitoring

Mobile apps for self-monitoring in bedsore prevention offer valuable tools for empowering individuals and caregivers to maintain skin health. These established technologies aimed at reducing the risk of developing pressure ulcers (PUs) in self-managed care focus on reducing pressure magnitudes and/or durations, such as reminding individuals to perform scheduled pressure relief or employing mechanisms to assist with repositioning (e.g., tilt function for powered wheelchairs). (Whitney et al., 2006) The choice of app should consider the user's specific needs and preferences as well as the app's features and integration capabilities. Patients and caregivers can use mobile applications designed to track and preventing bedsores. (Nair, Mathur, Bhandare, & Narayanan, 2020) These applications can provide reminders for positional changes, offer guidelines for skin care and hygiene, and track the progression of wounds.

Table 2 shows comparisons of the different solutions – smart mattress vs. wearable sensors vs. pressure mapping systems.

Table 2
Comparisons of the different solutions – smart mattress vs. wearable sensors vs. pressure mapping systems.

	Smart Mattress	Wearable sensors	Pressure mapping systems
Advantages	Sensors embedded within the mattress to monitor pressure points and detect changes in body position.	Provide mobility and flexibility since they may be worn by patients regardless of their location.	Pressure mapping technologies give extensive information on pressure distribution over the body's surface.
	Provide continuous monitoring without needing the patient to actively participate.	Detect pressure points in real time and can inform carers or patients to readjust if necessary.	Assist healthcare practitioners in tailoring interventions to meet the specific requirements of each patient.
	Also, these smart mattresses may be equipped with automatic repositioning to alleviate pressure.	Non-invasive and convenient for patients.	Useful for determining the efficacy of therapies and tracking changes over time.
Limitations	While smart mattresses provide continuous monitoring, they may be less precise in detecting early signs of pressure ulcers than more specialized sensors	The accuracy of wearable sensors might vary based on sensor location and patient mobility.	Pressure mapping systems often require specialised equipment and skilled workers to function properly.
	In addition, the initial cost of acquiring smart mattresses may be more than for alternative options.	Some patients may find sensors uncomfortable or forget to wear them regularly.	May not be appropriate for continuous monitoring or use outside of therapeutic settings.

Clinical evidences assessing effectiveness of preventive tools in bedsores

Clinical study on pressure mapping devices

A study titled "Pressure Map Technology for Pressure Ulcer Patients: Can We Handle the Truth?" (Pompeo, 2013) explored the implementation and impact of the pressure mapping technique in a long-term acute care (LTAC) facility in Northern Texas. This study aimed to evaluate the effectiveness of pressure mapping technology in preventing pressure ulcers among patients with existing ulcers or those at high risk of developing them. A pressure-sensing device, known as The MAP System, was used to monitor the pressure points and provide live feedback to the clinicians, facilitating timely repositioning and pressure relief. This study revealed the potential of pressure mapping equipment in the future to prevent hospital-acquired pressure ulcers and enhance wound healing. The study concluded that pressure mapping technology shows promise as a tool for preventing pressure ulcers by providing real-time feedback on the pressure distribution and guiding repositioning efforts.

Clinical study on wearable sensors

The LS-HAPI study (Pickham et al., 2018) demonstrated that wearable patient sensors effectively informed care delivery and improved turning compliance times and patient outcomes. Scientists have used randomization and discrete concealment techniques with individual opaque envelopes. Below the suprasternal crevice, a wearable sensor is affixed to the thorax. The wearable patient sensor measures patient rotation by evaluating its relative position within a three-dimensional space, and every ten seconds it transmits this information to a secure SQL database via a mesh network of antennae. The primary outcome was development of hospital-acquired pressure injuries. The clinical team independently performed the documentation and staging of pressure injuries. The total turning compliance time was the secondary outcome. If a turn was not conducted when expected (every two hours), any time past due was deemed non-compliant until the monitoring system detected a satisfactory turn.

In conclusion, among critically ill adult patients requiring admission to the Intensive Care Unit, optimal turning was higher with a wearable patient sensor, which increased the total time with turning compliance and demonstrated a statistically significant protective effect against the development of hospital-acquired pressure injuries.

Another Clinical Study to Validate Patient Repositioning Monitoring

Device to Prevent Pressure Ulcers (Minteer et al., 2020) demonstrated the Successful validation of PUMP1 pressure ulcer monitoring platform (PUMP1 and PUMP2) devices prototypes with 85% reliability in a 10-subject clinical trial. PUMP1 is a wearable electronic device that is attached to a patient with no skin contact. PUMP2 was a set of four identical electronic devices placed under the patient's bed wheels. A video camera recorded events in the patient room, and measurements from the PUMP devices were correlated with true patient repositioning activity. Immobility- or mobility-restricted patients were enrolled in the study. The repositioning movement was recorded by both PUMP devices for 10 ± 2 h and corroborated with video capture. One hundred thirty-seven movements in total were detected by both PUMP1 and PUMP2 after 105 h of capture. This study evaluated the ability of two different sensors to capture accurate patient repositioning to prevent PU formation. Importantly, detection of patient motion was completed without contact with the patient's skin.

Clinical study on pressure relieving mattresses

Alternative pressure in comparison with constant low-pressure

Eleven trials compared AP devices with different constant low-pressure (CLP) devices, but the results were unclear regarding which devices were better (Gebhardt, 1994), in a two-armed study, a variety of AP supports were compared to a variety of CLP supports in a variety of fields in acute care settings. The CLP group had significantly more pressure sores than did the AP group (34% vs. 13%) [RR, 0.38; 95% CI = 0.22 to 0.66].Nine randomized controlled trials (RCTs) comparing different types of AP supports and CLP devices, such as the Silicore overlay (Conine, Daechsel, Choi, & Lau, 1990; Daechsel & Conine, 1985; Stapleton, 1986), a water mattress (Andersen, Jensen, Kvorning, & Bach, 1982; Sideranko, Quinn, Burns, & Froman, 1992), a foam pad (Conine et al., 1990; Whitney, Fellows, & Larson, 1984), and static air mattresses (Price, Bale, Newcombe, & Harding, 1999; Sideranko et al., 1992); a viscoelastic foam mattress [including four-hourly turning and a sitting procedure with a cushion] (Vanderwee, Grypdonck, & Defloor, 2005); and the CLP method of the Hill-Rom Duo mattress (Cavicchioli and Carella, 2007), reported no difference in effectiveness, despite the fact that some were too small to be able to identify clinically substantial variations as statistically significant.

The results of all nine RCTs that compared different CLP and AP devices were combined to ascertain whether AP is more successful than CLP in preventing pressure ulcers. Although most studies found no significant differences between treatment groups, the use of AP mattresses was associated with an 80% chance of cutting expenditures. This was due to a delay in the development of pressure ulcers and a shorter hospital stay when AP mattresses were used.

Guidelines, contextual factors, and innovative technologies, combined with a comprehensive approach, can significantly lower the incidence of bedsores and increase patient comfort. It is essential to address pressure ulcer prevention and management with cost-effective measures to reduce economic burden and enhance patient outcomes. A cost-effective strategy for the prevention and management of pressure ulcers will include risk assessment, routine patient repositioning, use of support surfaces, and a proactive approach based on evidence-based practices, while considering the challenges and limitations when it comes to implementation.

Clinical study on patient position and frequent turning

In an observational study, patients were on their backs for nearly 50% of the time and turned to the left or right almost equally for the remainder. (Goldhill, Badacsonyi, Goldhill, & Waldmann, 2008) Results showed that it was rare for patients to remain flat, with only 2.3% of the observations in this position. Evidence suggests that nurses and other medical staff are reasonably accurate in estimating backrest elevation. However, in clinical practice achieving a semi recumbent position of 45° appears difficult. (Van Nieuwenhoven, Vandenbroucke-Graulls, & Van Tiel, 2006) Standardised orders and provider education may help increase the percentage of patients who are placed in this position. A study using a transducer system to monitor backrest elevation in 66 patients over 276 days found that backrest elevation was $<30°$ for 72% of the time and $<10°$ for 39% of the time. (Grap et al., 2005)

Clinical study on air fluidized therapy

Ochs et al. conducted a study that provided empirical evidence comparing pressure ulcer healing rates between different support surfaces and analyzed data from eligible residents with pressure ulcers (N = 664) enrolled in the National Pressure Ulcer Long-Term Care Study, which is a retrospective pressure ulcer prevention and treatment study. The support surfaces were categorized as follows: Group 1 (static overlays and replacement mattresses), Group 2 (low-air-loss beds, alternating pressure, and powered/non-powered overlays/mattresses), and Group 3 (air-fluidized beds). (Ochs, Horn, van Rijswijk, Pietsch, & Smout, 2005)

When calculating healing rates, using the largest ulcer from each resident, it was found that mean healing rates were greatest for air-fluidized therapy (Group 3) (mean = 5.2 cm^2/ week) versus Group 1 (mean =1.5 cm^2/ week) and Group 2 (mean = 1.8 cm^2/ week) surfaces (P = .007). Healing rates also were assessed using 7- to 10-day "episodes"; each ulcer generated separate episode(s) that included all ulcers when residents had multiple ulcers. Mean healing rates were significantly greater for Stage III/IV ulcers on Group 3 surfaces (mean = 3.1 cm^2/ week) versus Group 1 (mean = 0.6 cm^2/ week) and Group 2 (mean = 0.7 cm^2/ week) surfaces (Group 2 vs. Group 3: P = .0211). This finding persisted for ulcers with comparable initial baseline areas (20 cm^2 to 75 cm^2) on Group 2 and Group 3 surfaces; healing improved on Group 3 surfaces (+2.3 cm^2/ week) versus Group 2 surfaces (-2.1 cm^2/ week, P = .0399). Residents in Group 3 (6 out of 82; 7.3%) and Group 1 (47 out of 461; 10.2%) surfaces had fewer hospitalizations and emergency room visits than those in Group 2 surfaces (23 out of 121; 19.0%, P = .01), despite significantly greater illness in residents in Groups 2 and 3 versus Group 1 surfaces (P is less than 0.0001).

Despite the limitations inherent in retrospective studies, ulcers on Group 3 surfaces versus Groups 1 and 2 surfaces had significantly faster healing rates (particularly for Stage III/IV ulcers) with significantly fewer hospitalizations and emergency room visits (Group 3 versus Group 2), despite significantly more illnesses in residents in Group 2 or Group 3 than in Group 1. Episode analyses, providing greater power, uniform treatment duration, and comparable baseline sizes, confirmed these findings. Air-fluidized support surfaces represent great healing potential. (Ochs et al., 2005)*Clinical trial on pressure monitoring system in wheelchair bound individuals*

Fard et al. conducted a comprehensive analysis focusing on the monitoring and detection of sitting posture to assess the risk of pressure ulcer development in individuals who were dependent on wheelchairs. A continuous pressure-monitoring system was developed to address the issue of pressure ulcers. This system consists of a sheet equipped with 64 pressure sensors over an area of 40×50 cm^2, enabling real-time collection and display of pressure data and corresponding maps on a computer interface. Furthermore, this study proposed a posture detection procedure designed to accurately identify sitting postures. Access to historical postural data through this system allows caregivers to make informed decisions regarding the repositioning and treatment of patients.

The introduction of proactive posture monitoring has been shown to significantly mitigate the risk of pressure ulcers in wheelchair-bound individuals. By utilizing systems for sitting posture identification, healthcare providers and caregivers can anticipate the potential development of pressure ulcers, thus enhancing the care and overall well-being of those who use wheelchairs. These findings highlight the critical role of innovative technological solutions in healthcare, which enhance preventive strategies and reduce the prevalence of pressure ulcers among vulnerable populations. (Fard, Moghimi, & Lotfi, 2013)

Clinical study on telemedicine for preventing and treating pressure injury after spinal cord injury

Telemedicine is a viable means of preventing pressure injuries in patients with spinal cord injuries. Without placing excessive financial strain on the patients, it can hasten their recovery and reduce the frequency and severity of pressure injuries. A systematic review of 35 studies comprising 25 randomized controlled trials and 10 quasi-experimental studies involving 3131 patients was conducted to evaluate the effectiveness of telemedicine in preventing and treating pressure injury among community-dwelling patients with spinal cord injury, and to determine which telemedicine form is more effective. The results showed that telemedicine significantly ($P<.05$) reduce the incidence of pressure injury (RR 0.24, 95% CI 0.14–0.41; $P<.05$; I2=0%), promoted faster healing (RR 0.73, 95% CI 0.62–0.85; $P<.05$; I2=0%), and yielded lower scores on the pressure ulcer scale of healing (weighted mean difference=–1.98, 95% CI –3.51 to –0.46; $P<.05$; I2=0%). Cumulative ranking estimates showed that combining telemedicine with conventional intervention (93.5%) was the most effective approach. (Chen et al., 2022)

Vesmarovich et al. conducted a study to determine whether wound care via telerehabilitation was a viable alternative to clinic visits. Telerehabilitation is the use of telecommunication technology to deliver rehabilitation services at a distance. Eight patients were followed up in the outpatient clinic. The Picasso Still-Image Videophone was used to capture and send images from the patients' homes to the clinic. Findings from the exploratory study demonstrated that pressure ulcers can be successfully managed via telerehabilitation. (Vesmarovich, Walker, Hauber, Temkin, & Burns, 1999) Carlson et al. conducted a single-site, single-blind, randomized controlled study that compared a lifestyle intervention entitled the Pressure Ulcer Prevention Program (PUPP) with usual care. The study results reported that telemedical support from a multidisciplinary team can provide rehabilitation, nutritional suggestions, and psychological guidance, as well as how to deal with the threat of pressure injury. When a discharged patient has health-related problems, they can receive appropriate help over time. Effort should be devoted in clinical practice to promoting multidisciplinary team cooperation and comprehensively promoting the physical and mental recovery of patients with spinal cord injury (SCI). (Carlson et al., 2019)

Potential benefits of pressure monitoring technologies

The study conducted as part of the multicenter, UK-based PRESSURE trial demonstrated the economic viability and clinical effectiveness of alternating pressure mattresses over overlays. The mattresses not only reduced hospital costs by an average of £283.6 per patient but also delayed the development of pressure ulcers by approximately 10.64 days. These findings suggest that pressure monitoring technologies can significantly enhance patient care by preventing pressure ulcers more effectively and reducing healthcare costs. (Iglesias et al., 2006)

Economic and accessibility challenges

Despite their benefits, the implementation of advanced pressure monitoring systems faces significant economic and accessibility challenges. The high costs associated with acquiring and maintaining such technologies pose substantial financial burdens, particularly in resource-limited environments. Accessibility issues may also arise, limiting the widespread adoption of these potentially life-saving technologies.

Training and integration challenges

Integrating these technologies into existing healthcare workflows requires extensive training for healthcare professionals. It is crucial to ensure that all personnel are proficient in using the technology and can seamlessly incorporate it into their daily routines. Developing comprehensive training programs and continuous education initiatives is essential for successful implementation. (C. Shi et al., 2021)

Risks of technological overreliance

There is a risk that an overreliance on technology could lead to complacency among healthcare providers. Technological malfunctions could compromise preventive efforts if not adequately addressed. To mitigate these risks, it is important to maintain a balanced approach that includes manual checks and traditional care practices alongside the use of technology. (Hofman et al., 1994)

Implementation strategies

For effective implementation, healthcare facilities must adopt a thorough methodology that includes collaboration among nurses, doctors, wound care specialists, and technology experts. Creating standardized procedures for nutritional assessment, wound care, and patient management will support the integration of technology. Additionally, investing in infrastructure—such as reliable IT support and equipment maintenance—is crucial for sustaining technology use. Continuous quality improvement initiatives should be established to assess outcomes and facilitate ongoing enhancements in care practices. (C. Shi et al., 2021; C. Shi et al., 2021)

Conclusion

Technology-driven solutions offer promising avenues for preventing bedsores and improving patient outcome. Their effectiveness in reducing the incidence of bedsores, improving patient comfort, and enhancing cost-effectiveness is evident in various studies. However, it is essential to recognize that technology should be a complementary approach to traditional prevention strategies rather than a complete replacement. Addressing the challenges associated with technology adoption, focusing on cost-effectiveness, and integrating these solutions responsibly into clinical practice will pave the way for more successful bedsore prevention initiatives.

Further research should focus on long-term clinical trials in order to evaluate the sustainability of technology-based preventive strategies. Efforts should be made to make these technologies more affordable and accessible to health care facilities worldwide. Collaboration among researchers, clinicians, and technology developers is the key to driving innovation and maximizing the potential of technology for bedsore prevention.

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Pallabi Ghosh: Writing – original draft, Methodology, Investigation. **Pritheevi Raj N:** Writing – original draft, Methodology, Investigation. **Vachana M N:** Writing – original draft, Methodology, Investigation. **Pavish S R:** Writing – original draft, Methodology, Investigation. **Prathibha Pereira:** Writing – review & editing, Supervision, Resources, Project administration. **Tejeswini C J:** Writing – review & editing, Supervision, Resources, Project administration. **Madhan Ramesh:** Writing – review & editing, Supervision, Resources, Project administration. **Jehath Syed:** Writing – review & editing, Supervision, Project administration. **Sri Harsha Chalasani:** Writing – review & editing, Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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