Design and Implementation of a Novel Double-Layered Wavy Mattress for the Prevention and Recovery of Pressure Ulcers: A Feasibility Study

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ABSTRACT

Pressure ulcers are a significant concern in patient care, particularly for those with limited mobility and extended hospital stays. Wavy mattresses are shown an effective tool for preventing or promoting the healing of these wounds by preventing pressure localization in different body regions. The current study aimed to present a novel double-layered wavy mattress design for the prevention and recovery of pressure ulcers, addressing some of the limitations of existing mattresses. The novel mattress includes double-layered cells, with the upper and lower layers, filled with water and air, respectively. The temperature of water in the cells can be manually adjusted to meet patients' needs, prevent skin sweating, regulate body temperature, and promote blood flow in areas susceptible to pressure ulcers. Patients who used this novel mattress during their hospitalization experienced a significantly shorter recovery period for bedsores compared to those who used other mattresses, showing that the novel wavy mattress is an effective tool for preventing and recovering from pressure ulcers in long-term hospitalized patients with limited mobility.

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Keywords

Hospitalization; Pressure Ulcer; Wavy Mattress; Temperature; Sweating

Introduction

A pressure ulcer, also known as a bedsore, is a significant health concern for patients in hospitals; it is characterized by skin and tissue damage resulting from prolonged pressure or friction on specific parts of the body [1]. Bony areas that support body weight in various positions are particularly vulnerable, such as the elbows, back, shoulders, and sacrum [2]. Continuous pressure on these areas can lead to the development of pressure ulcers and, in severe cases, tissue necrosis [3].

There are several risk factors related to the occurrence of bedsores, such as inactivity, immobility, skin moisture, nutrition, temperature [1], demographic factors, body weight, and anemia [3]. Additionally, the lack of blood flow and the destruction of existing tissues due to pressure, heat, and sweating of the body can cause bedsores in the body, especially in long-term hospitalized patients [3].

Given the pain and potential dangers associated with pressure ulcers, preventive measures are crucial and more cost-effective than treatment

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[1, 3]. Educating healthcare personnel, implementing proper skin care practices, utilizing prophylactic dressings, ensuring appropriate patient positioning, promoting early patient mobilization, and using support surfaces are among the most effective prevention methods [1]. Pressure ulcers through preventive policies and practices have to be addressed to reduce the incidence of these wounds, patient suffering, and healthcare costs.

The support surfaces, such as cushions, integrated bed systems, and mattresses, are optionally used to prevent bedsores in hospitalized patients [1, 3]. Among these options, a corrugated mattress can be particularly used. Corrugated mattresses have dynamic and alternating air pressure inside their wavy structure to prevent the formation of pressure ulcers. However, a significant drawback of existing corrugated mattresses is their inability to detect and adjust for factors like body temperature, affecting blood flow and pressure distribution in different areas [2].

Pressure ulcers pose a potential risk to patients in specialized care units, resulting in prevention a critical aspect of nursing and hygiene [4]. To address the limitations of existing mattresses, this study aimed to develop a new double-layered wavy mattress. This innovative design not only redistributes pressure effectively but also incorporates temperature measurement and adjustment capabilities. Integrating temperature monitoring and regulation into the mattress can enhance the prevention of pressure ulcers more effectively.

The development of such an innovative mattress can improve patient care and reduce the incidence of pressure ulcers in hospitalized individuals. The additional factors, such as body temperature and incorporating smart technologies into the design can lead to providing a more comprehensive and proactive approach for preventing pressure ulcers.

Material and Methods

In this design & feasibility study, a novel double-layered mattress is designed and implemented.

Design and Fabrication

The novel wavy mattress design features double-layered cells, as depicted in Figure 1. Layer A serves as the upper layer, connected to a water control pump. This connection aims to regulate the temperature of the flowing water, catering to the specific temperature needs of each individual patient. By leveraging the principles of heat transfer and Newton's law of conduction, the mattress can effectively control the patient's body temperature, expressed with the following Fourier formula, as follows [5]:

$$\frac{q_x}{S} = -h\frac{\partial T}{\partial x} \qquad \text{(Equation 1)}$$

where, q_x is the conductive flux in a specific direction like x (ratio of heat to the surface), which is proportional to temperature changes in that direction; h is the coefficient of thermal

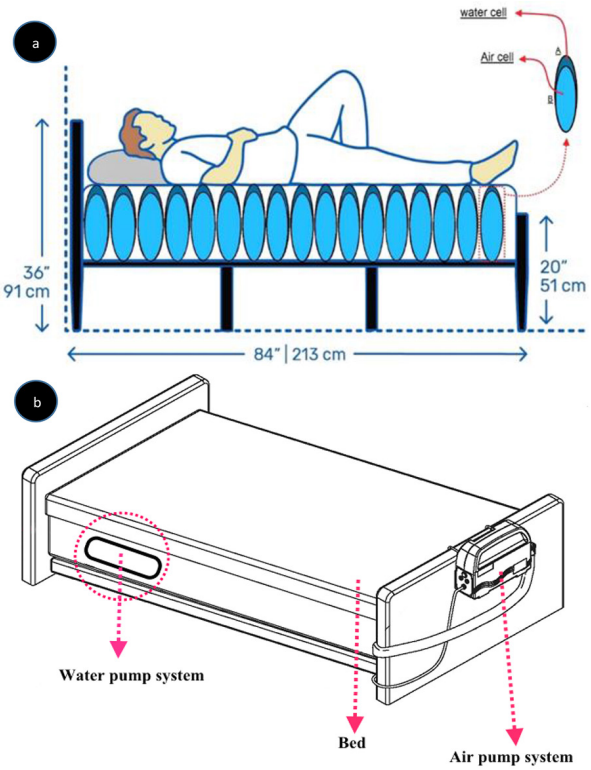

Figure 1: The schematic of the novel double-layered wavy mattress, a: air (A) & water (B) filled cells. b: other main components.

conductivity that can be constant or variable with temperature; S is the area of the surface perpendicular to the flow direction, and $\frac{\partial T}{\partial x}$, the temperature gradient, is equal to the temperature changes compared to the thickness of the wall or the contact surface. The negative sign in the relationship is due to the reductive temperature changes, and heat transfer is always from higher to lower temperature objects.

Layer B, constituting the lower layer of the mattress, consists of air-filled cells, similar to conventional wavy mattresses. This layer is connected to an air compressor, ensuring the pressure distribution and preventing the concentration of pressure in areas prone to ulcers.

To monitor the temperature, multiple LM35 temperature sensors (Texas Instruments, Dallas, Texas, USA) are incorporated into the upper layer of the mattress. These sensors also measure the water temperature, which is then displayed on a screen. Users, including patients, nurses, and hospital staff, can control the temperature through this screen. The water temperature in Layer A cells can vary within a range of ±5 °C compared to the normal body temperature of 37 °C. To facilitate cooling, an aluminum radiator is embedded between the layer A cells. Additionally, a heating element inside the water tank is utilized to warm the water when needed.

Throughout the design and manufacturing process, cost-effectiveness has been a priority. The current study aimed to utilize affordable devices with the highest possible efficiency, ensuring that the product remains economically viable.

In the design and manufacture of this product, the cheapest devices are used with the highest efficiency wherever possible, leading to a cost-effective product.

Implementation

In the current study, the novel wavy mattress was successfully fabricated and placed in the infections department of Imam Reza Hospital in Kermanshah, Iran. This department primarily catered to patients who required hospitalization due to conditions, such as amputation, surgery, and diabetic infections, all of whom were at a higher risk of developing bedsores. The implementation of the wavy mattress aimed to provide these patients with an effective preventive measure during their hospital stay.

Figure 2 illustrates the four stages of pressure ulcers, as follows: 1) no breaking or tearing in the skin, but the affected area exhibits

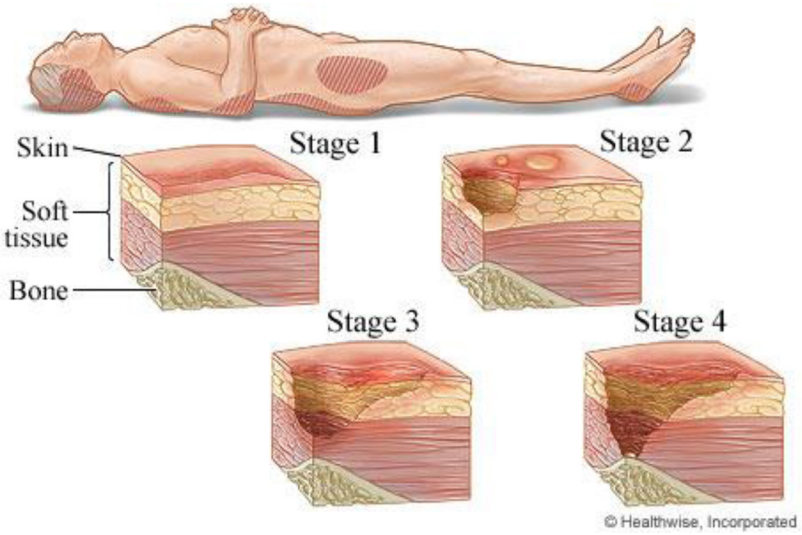

Figure 2: Classification of pressure ulcers. (The image is taken from: https://myhealth.alberta.ca)

soreness, pain, inflammation, redness, or discoloration, 2) involving a shallow opening of the upper layer of the skin, reaching the soft and fatty layer underneath. The wound appears as a pinkish-red ulcer without infection or bleeding, which is typically painful and healed 3 to 21 days after the removal of pressure, and 3) and 4) depicting more severe ulcers, in which the wounds extend deeper into the tissue. These stages require several months for complete healing and necessitate specialized care, including medication and potentially surgical intervention [2].

During 18 months, more than 80 patients who were hospitalized in the infectious department of Imam Reza Hospital, Kermanshah, Iran, were surveyed, and patients with stage 3 and 4 ulcers were excluded, resulting in 80 patients at the end. A total of 40 patients used the novel wavy mattress (group A), and others used a normal wavy mattress (group B). In each group, 33 and 7 patients had stage 1 and 2 ulcers, respectively. Also, the distribution of the ulcer sites was almost the same in the 2 groups.

Results

The effectiveness of the novel wavy mattress was evaluated during the implementation phase. The patients included had either stage 1 or stage 2 pressure ulcers, comprised of 27 females and 13 males, with ages ranging from 41 to 60 years old. The distribution of ulcer sites among the patients is provided in Table 1.

All of the patients were prescribed antibiotics, anti-inflammatory, and sedative (painkiller) drugs. Table 2 compares the duration of betterment in groups A & B patients with different pressure ulcer stages.

Pressure ulcers are a significant concern in the care of long-term hospitalized patients, typically developing due to compromised blood supply in areas subjected to prolonged pressure [3]. Figure 3 shows the most likely areas, in which bedsores occur in the most common positions of hospitalized patients.

The latest wavy mattresses are designed with an integrated air compressor system, automatically adjusting the pressure inside the mattress cells based on the concentration of pressure in different areas of the patient's body. This dynamic pressure redistribution mechanism ensures that pressure is relieved from specific points and evenly distributed across the surface of the patient's body. By preventing excessive pressure build-up in certain areas, the risk of developing pressure ulcers is significantly reduced.

The air compressor system regulates the air pressure within the cells, optimizing comfort and pressure relief for the patient (Figure 4).

According to Table 2, our novel wavy

Table 1: The distribution of the ulcer sites in the studied population.

Ulcer site	Number (percent)
Sacrum	36 (45%)
Shoulder & elbow	17 (21%)
Foot & ankle	12 (15%)
Other regions	15 (19%)

Table 2: The recovery duration of patients in groups A (using the novel wavy mattress) and B (using the normal wavy mattress).

Ulcer stage	Mean recovery duration in group A (days)	Mean recovery duration in group B (days)	Definition of recovery
Stage 1	3	5	Fading skin redness
Stage 2	10	20	Changing the ulcer stage from 2 to 1

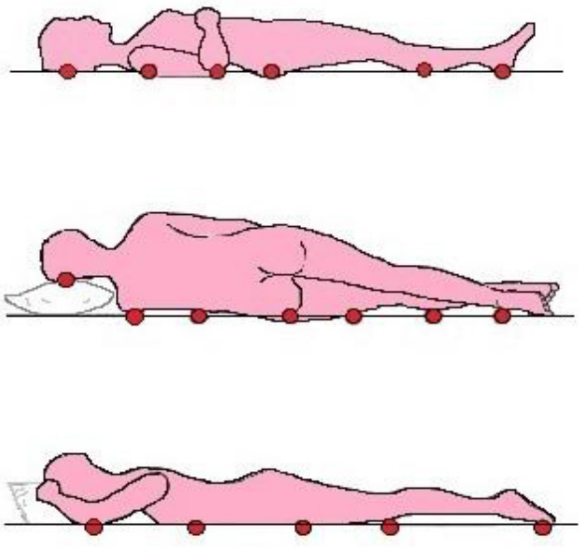

Figure 3: Points of the body where the pressure is concentrated.

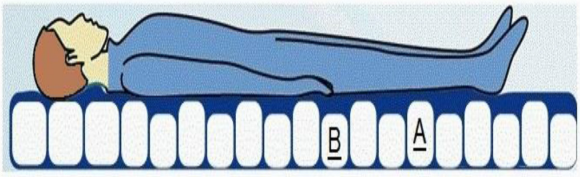

Figure 4: Outline of a typical wavy mattress

mattress has the potential to reduce patients' hospitalization time by nearly half, indicating its potential to expedite recovery and improve overall patient outcomes.

Discussion

The current study aimed to present a novel double-layered wavy mattress design for the prevention and recovery of pressure ulcers. As depicted in Figure 4, the wavy mattress with two separate pressure cells effectively distributes the weight of the patient across different parts of the body. In this configuration, cell bears the weight and provides pressure relief, while cell B remains decompressed without any weight. This design prevents prolonged pressure on a single point [6]; however, pressure alone is not the sole cause of bedsores. Skin moisture and body temperature also play significant roles [1]. In hospital settings, multiple patients are often housed in a single room with a uniform temperature and humidity level, which may not meet the individual needs of each patient at different times, leading to sweating in some patients while others feel cold in the same room [7].

The novel wavy mattress addresses these challenges by incorporating water-filled cells that enable individual control of each patient's body temperature. The water in these cells can be heated or cooled as needed, optimizing humidity and temperature conditions based on each patient's requirements. This approach eliminates the need to adjust the entire room's temperature, saving time and energy. Furthermore, the novel wavy mattress aimed to enhance blood flow in different body regions by controlling skin moisture and body temperature. Blood flow is crucial for the prevention and healing of pressure ulcers, an aspect, which conventional wavy mattresses are unable to address (Table 2).

Conclusion

The novel double-layered wavy mattress is considered an effective preventive and therapeutic solution for pressure ulcers. It not only provides the same advantages as traditional wavy mattresses but also addresses significant limitations. Additionally, energy efficiency is promoted for patients with limited mobility during hospitalization, and the length of hospital stays is decreased. The adverse effects of prolonged confinement are mitigated, such as the occurrence or deterioration of pressure ulcers. The present study aimed to enhance and advance existing wavy mattresses by improving their functionality and efficacy.

Acknowledgment

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Kermanshah Iran, for their valuable cooperation and support throughout the implementation of this project.

Authors' Contribution

Regarding the authors' contributions, M. Ghaderi played a pivotal role in designing the product and overseeing the fabrication of the prototype. All authors actively participated in data collection, writing, and reviewing the manuscript, ensuring a comprehensive and well-rounded study. All the authors read, modified, and approved the final version of the manuscript.

Conflict of Interest

None

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