

## Design of Anti-Bedsore Hospital Bed

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### **Abstract**

An anti-bedsore bed is a medical device that prevents or delays occurrence of pressure ulcers by alleviating contact pressure exerted on a patient due to a contact with a bed. Normally a patient recovering in bed for an extended period of time will experience pressure ulceration due to insufficient blood flow to tissues in the areas that carry body weight. In this work, an extra bed set to be installed on a generic hospital bed has been designed to prevent pressure ulcers with a mechanism to change points of contact between body of patient and bed. The bed set consists of four sections for supporting a patient's head, hip, thighs and heels. Changes in pressure on the patient's body due to the movement of the bed set are measured by pressure films, and results are used in the assessment of the bed's capability to prevent pressure ulcers by benchmarking with a risk curve for pressure ulcers in the literature. The test results confirm that the extra bed set can prevent pressure ulcers if the bed set operates at a 15-minute cycle.

**Keyword:** Pressure Ulcers, Bedsore, Hospital Bed, Anti-bedsore

### **1. Introduction**

Bedsore or pressure ulcers are localized injuries to skins and/or muscles caused by insufficient blood flow in weight-bearing areas, e.g., hip and heels, of bed-ridden patients. High moisture and high temperature increase the rate of occurrence of bedsore. Severity of bedsore depends on the magnitude and the duration of pressure exerted on a patient's body. Though curable if detected, pressure ulcers are a main cause of injuries for unassisted patients who are confined in beds or wheelchairs. A typical recommendation for prevention of bedsore is to roll over the patient every two hours to alleviate

contact pressure. Some patients who recuperate at home need to expensively hire a personal caretaker to do this work. Such luxury is not available for poor patients.

An alternative method to reduce the risk of pressure ulcers is to embed a mechanism that helps relieve pressure on the patient's body. A variety of anti-bedsore products is commercially available. These products can be broadly categorized into passive and active mechanisms for relieving pressure. The passive mechanism redistributes pressure in a given area using pressure sensitive support that changes stiffness with respect to the patient's body movement.

Fig. 1 shows an example of fluid-filled cushion for neck support [1, 2]. These passive anti-bedsore products are economical because they do not have moving parts. However, they are not suitable for patients suffering from full body paralysis, and in active patients the products only delay occurrence of pressure ulcers.

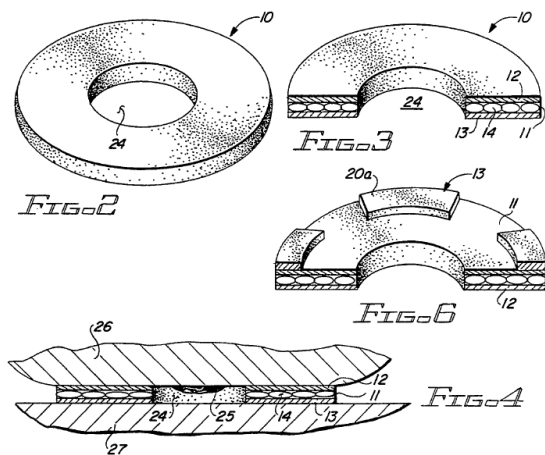


Fig. 1 Fluid-filled cushions for neck support [1]

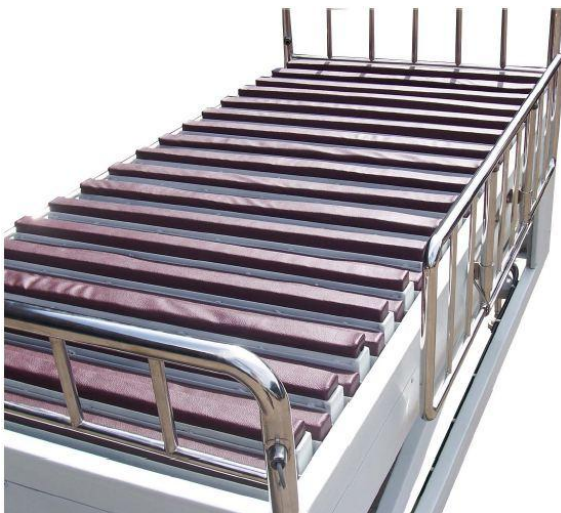


Fig. 2 A partitioned surface [3]

Anti-bedsore products with active mechanism reduce risk of pressure buildup by moving points of contact between the patient and the support. A swinging mechanism that gently rolls over the patients [4-7] can be embedded in bed. Yet, a

swinging motion can cause the patient's body to slide sideways, hurting and damaging the patient's skin. Another active mechanism is a bed with a partitioned surface that can be an embedded structure or a supplemental pad to be placed on a regular hospital bed [3]. Vertical movements of these separate partitions alternate points of contact between the body and the bed surface. The partitions can be driven using pneumatics [8], hydraulics [9] or mechanical actuators [10, 11].

In Thailand, a pneumatic anti-bedsore pad made of rolls of inflatable plastic bags appears to be one of the most popular models because of its light weight, adaptability to a variety of hospital beds and economical price. However, inflatable bags are susceptible to leakage, either by being pierced by sharp medical devices, e.g., needle, or by the aging of the plastic itself. Another popular anti-bedsore mechanism is a mechanical patient bed embedded with a set of two steel frames moving vertically to alternately support the patient's body. Such design has been proposed by a renowned Thai surgeon, Dr. Yanin Authayopath [3], and now there exist many variations thereof. The steel frame design has a longer service time and it is less prone to accident compared to inflatable bags, but it is costlier and possibly less comfortable. Embedded mechanism in the bed also has a drawback in its lack of mobility due to the weightiness of the driving parts.

The objectives of this work is to design a new anti-bedsore mechanism such that shortcomings of existing products, for example, leakage of inflatable bags or limited adjustability of rigid frame, are fully addressed. The proposed design

is an extra bed pad to be installed on top of a regular hospital bed. It consists of four sections of partitioned steel frames corresponding to four main weight-carrying areas of the body: head, hip, thighs and heels. Each set can work independently, but its movement is controlled from a central automatic control board. Thus, all frames work in a synchronized programmable pattern.

## 2. Design Requirement of Anti-Bedsore

### Mechanism

#### 2.1 Risk of Pressure Ulcers: Pressure-Time Relation

Pressure ulcers occur from insufficient blood flow in tissues that have been under constant pressure either by the patient's weight or by contact of sharp bony area, such as the heel bone or the malleolus bone. The risk of pressure ulcers depends on both magnitude and exposure time of pressure on the injured area. Fig. 3 obtained from [12] shows a set of pressure-time curves that demonstrate the threshold of pressure ulcers in mammals [13-18]. The area above each curve indicates pressure-time combinations where there are risks of experiencing pressure ulcers for each corresponding mammal, whereas that below the curve is considered safe. Note that all curves in Fig. 3 are hyperbolic. Thus, a low level of pressure that is applied for an extended time is as harmful as a high level of pressure applied for a short time. Among all data, only the study by Reswick and Roger [15] is related to pressure ulcers in human. This study was obtained from measuring the skin-cushion interface pressure in 800 human volunteers and estimating the

relationship between the magnitude and the exposure time for volunteers to whom pressure ulcers occur, and that for those without pressure ulcers. Therefore, the data of Reswick and Roger serve as a preliminary benchmark to the pressure-exposure time behavior.

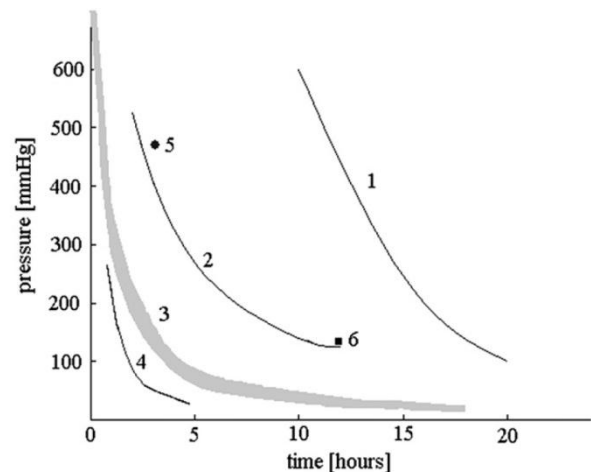


Fig. 3 Risk curves regarding pressure ulcers.

Pressure vs. Time combinations above the curve results in tissue breakdown. 1. Daniel (swine, 1981) [13], 2. Kosiak (dog, 1959) [14], 3. Rogers (human, 1973) [15], 4. Kosiak (rat, 1961) [16], 5. Dinsdale (swine, 1973) [17], 6. Salcido (rat, 1994) [18]

#### 2.2 Design Requirements

The anti-bedsore design must meet the following list of requirements compiled from perspectives of medical standards, user preference, manufacturing process and marketing. Requirements compiled from medical standards and users' safety are:

- no harmful chemical substance,
- ability to perform cardiopulmonary resuscitation (CPR),
- acceptable level of noise, and
- good ventilation.

Requirements for user preferences are:

- automatic and continuous operation,
- low maintenance.

Engineering requirements are:

- easy to manufacture and assemble,
- adjustable operating cycle from 5 minutes to 2 hours,
- long service time.

Marketing requirements are:

- differentiation from existing products,
- ability to serve as a supplement to standard hospital bed,
- reasonable price.

### 3. Proposed Anti-Bedsore Design

#### 3.1 Design Details

Based on the requirements, an anti-bedsore bed set, shown in Fig. 4, is designed with four independent sections as supports for back, hip, thighs and heels of a patient. These sections are to be fixed on surface of a generic hospital bed.

This design employs a change in pressure point mechanism by vertical movement of partitioned cushion. The structure is reinforced with structural steel frames for stability.

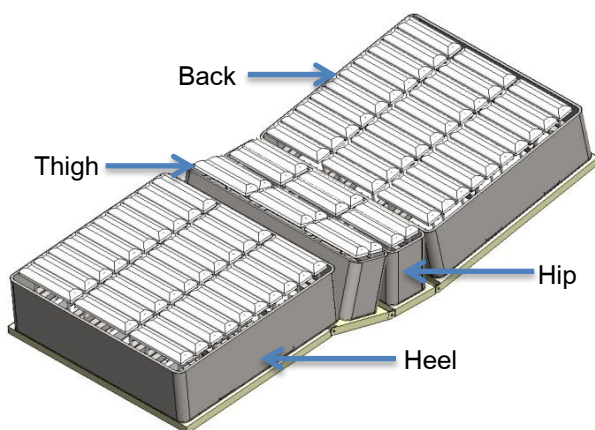


Fig. 4 Anti-bedsore bed in four sections: back, hip, thigh and heel.

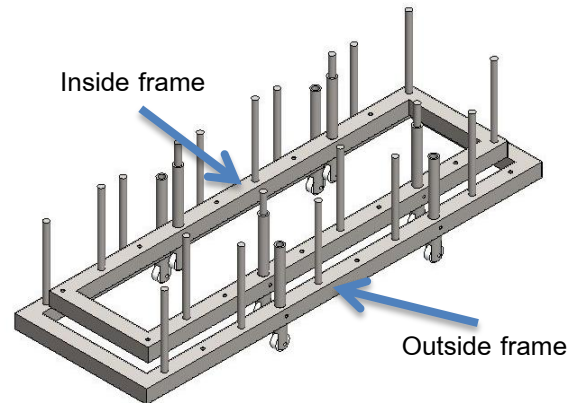


Fig. 5 Inside and outside frame of anti-bedsore bed in back and heel sections.

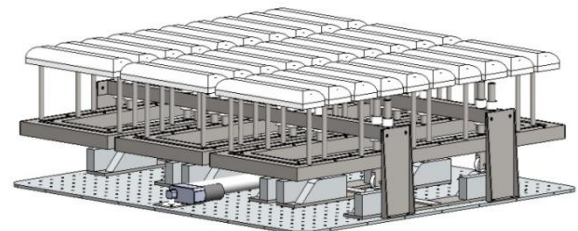


Fig. 6 Structure of anti-bedsore bed set - back and heel sections.

The back and the heel sections of the hospital bed generally have the same dimensions. Thus, the anti-bedsore bed for these sections share an identical design consisting of three sets of two coplanar rectangular steel frames where one 'outside' frame surrounds another 'inside' frame, see Fig. 5. Cushions are attached on top of all frames in an alternating pattern between inside and outside frames and between neighboring sets of frames. Gaps between cushions ensure good air ventilation as well as provide spaces for inspection, installation and maintenance of the structure. Each frame has a set of rollers that are placed on a moveable inclined plane. When the inclined plane is displaced in parallel to the surface of the bed the rollers move up or down the inclined plane,



resulting in a vertical motion in a checkerboard pattern of the cushions.

On the hip and the thigh sections of the hospital bed generally have a limited space compared to the back or the heel sections. Thus, the anti-bedsore bed for these sections requires a compact design consisting of two coplanar steel frames similar to those in the back section. Each frame is driven vertically by a motor and a set of power screws. Fig. 7 shows the structure of an anti-bedsore bed in the hip and thigh sections.

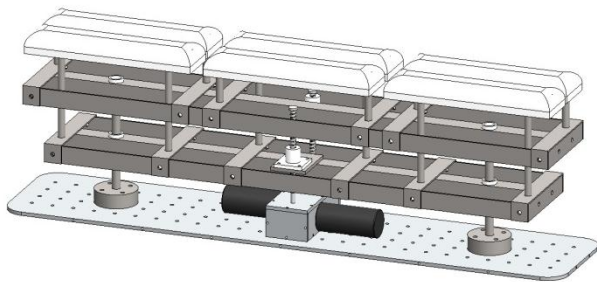


Fig. 7 Structure of anti-bedsore bed set - hip and thigh sections.

Actuators in all sections are centrally controlled by a custom-made control board so that the cushions move in the vertical direction in a checkerboard pattern as shown in Fig. 8. There are four steps in each operating cycle:

1) both inside and outside frames of all sections move up to create a leveled plane for the patient's body,

2) the inside frames drop down by moving an inclined plane for the back and the heel sections or by motor for the hip and thigh sections,

3) the inside frames move up to the leveled plane, and

4) the outside frames drop down.

A cycle of these steps causes changes in contact pressure at the patient-bed interface. The downward movement of the frames in steps 2) and 4) keeps the patient's body stationary while the weight is being redistributed. The downward movement is preferred to the upward movement because protruding cushions caused by the upward movement can press against the patient's body, making the patient uncomfortable resting on the bed.

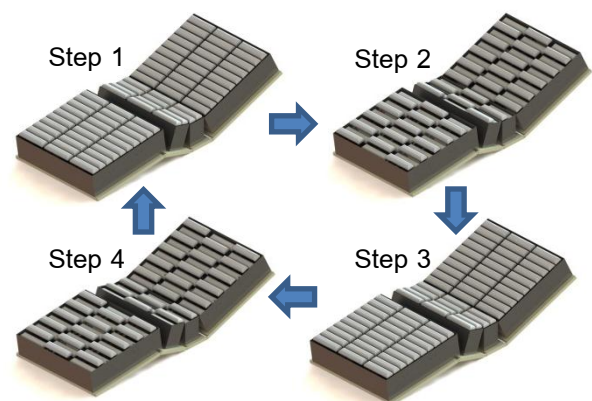


Fig. 8 Movement of the cushion.

The proposed anti-bedsore bed set differs from pressure pads and embedded mechanical structure by having four rigid sections instead of a one-piece of equipment. Versatility from having separate sections allows for installation of the system onto any generic hospital. Further, maintenance and replacement can be done on a per-section basis because they independently operate.



Fig. 9 Installation of the anti-bedsore bed with a general hospital bed and the mechanisms within the anti-bedsore bed.

To ensure product safety, strength of the structural frames is analyzed in CAD-built-in finite element software. Results of the analysis show that the steel structural frame can easily withstand a patient's weight of 200 kg.

### 3.2 Specification of anti-bedsore bed

- Dimension: W x L x H = 100 x 220 x 90 cm
- Total weight (add-on anti-bedsore + hospital bed): 320kg
- Maximum Load on each section: 100kg
- Operating cycle: 5 – 120 minutes

## 4. Fabrication, Validation and Limitations

### 4.1 Fabrication of anti-bedsore bed

A prototypical anti-bedsore bed has been manufactured according to the design. The bed set is attached to a commercial hospital bed as

shown in Fig. 9. Its internal driving mechanisms are also illustrated in Fig. 9. A preliminary testing of the functionality of the bed has been favorably proven.

### 4.2 Validation of anti-bedsore bed

To validate the anti-bedsore capability requires extensive medical trials of potential pressure ulcers patients. However, such procedure is beyond the scope of this current report. Alternatively, the anti-bedsore capability of the design is verified by measuring pressure distribution on the patient's body and using these parameters to assess the possibility of getting pressure ulcers by comparing to the pressure-time curves for getting pressure ulcers.

Pressure distribution at the bed-patient contact surface is measured by a pressure measurement film by Fujifilm (Extreme low

pressure film (4LW): measuring pressure range 0.05-0.2 MPa or 375-1500 mmHg). An 80-kg male subject lies on the partitioned cushion at a leveled surface (step 1), when the lower frame is lowered (step 2), and when the outside frame is lowered (step 4). Resulting pressure distribution is illustrated in terms of variations in color density. Focus should be especially given to the pressure exerted on the hip because this part of the body accounts for approximately 50% of human weight while lying down. Fig. 10 shows a hypothetical loading condition for each step and its corresponding pressure distribution.

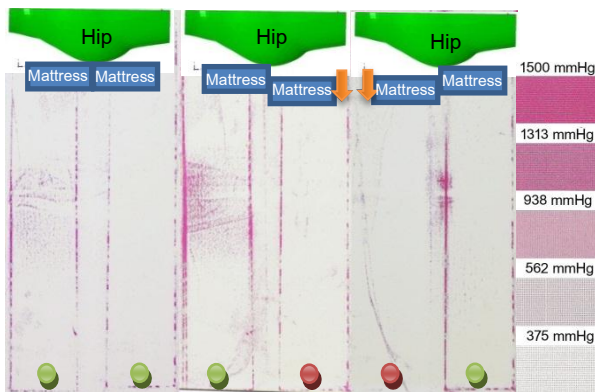


Fig. 10 Pressure distribution on the patient due to movement of the anti-bedsore bed.

The results show the magnitude and the location of pressure exerted on the subject's hip. The anti-bedsore bed alters the location of pressure with the movement of the cushions. When the subject is rested on a leveled surface, the pressure on the patient is less than 375 mmHg. Had the subject remained at the same position, pressure ulcers would have occurred. When either the inside or outside frames are lowered, the pressure at contact surface is increased to approximately 560 mmHg. According to data by Reswick [15], a 560mmHg pressure

will cause pressure ulcers if loaded for more than 20 minutes. Hence, an optimal operating cycle for this patient is to operate at a 15-minute cycle. Note that this measurement is still an approximation due to a poor resolution of pressure measurement film. A more refined measurement using pressure sensor pad is still needed for further verification.

#### 4.3 Limitations of anti-bedsore bed

There are still a few limitations of this design. First, a large number of moving parts are required, which lead to a long assembly time. These parts can be manufactured en mass or pre-assembled to reduce the manufacturing time. Second, parts of the patient's body may accidentally be trapped in gaps between cushions. This problem is currently rectified by having a custom-made thin cover pad that covers the entire surface of the bed and provides aesthetic look to the bed set. Lastly, the proposed mechanism redistributes pressure on a patient's body by changing the contact location. Test results show that changing location of support may lead to pressure concentration. If the operating cycle time is not carefully controlled, this concentrated level of pressure can become a source of pressure ulcers instead of curing it. Thus, a careful consideration of operating procedure is to be determined.

#### 5. Conclusion

An anti-bedsore bed set is designed and manufactured to supplement standard hospital bed. An automatic anti-bedsore bed can change the pressure point and support the patient's weight of more than 100 kg. Its ability to prevent pressure ulcers is verified by testing pressure

distribution in a test subject. The results show that the anti-bedsore bed must be set to a 15-minute cycle to successfully prevent pressure ulcers.

## 6. Acknowledgement

This research work is financially supported by Ministry of Science and Technology, and National Metal and Materials Technology Center.

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