

ABSTRACT:

Bedsore — also called *pressure ulcers* or *decubitus ulcers* — are injuries to skin and underlying tissue resulting from prolonged pressure on the skin. For permanently bedridden patients (especially those paralyzed or in coma), bedsore are a problem which are usually either ignored or not dealt with properly. The effects of bed sores can be very severe when it reaches higher stages (stage 3, stage 4) below the surface of the skin even exposing the bones. The causes of bed sores are pressure, shear and friction where pressure plays a major role and hence are known as *pressure ulcers*. When a person lies on a bed for a prolonged period of time, pressure at body parts such as tailbone, shoulder blades, heels, ankle, skin behind knees restricts blood flow at these points which in turn results in sores. Taking care of patients affected by bedsore is a trying process for the nurses or the care-taker. Either by distributing the pressure throughout the body or by shifting the pressure points frequently the occurrence of bed sores can be delayed or prevented. *Hypnos* employs the latter principle to prevent the development of bedsore by attaining five different positions.

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Introduction:

Bedsore, otherwise known as the *pressure ulcers* or *decubitus ulcers*, are injuries to skin and the underlying tissues resulting from prolonged pressure on the skin. Bedsore most often develop on skin that covers bony areas of the body.

It is estimated that an average human shifts the sleeping position for every 11.6 minutes to *prone*, *lateral recumbent* or *supine* positions. So, people most at risk of bedsore are those with a medical condition that limits their ability to change positions or those who spend most of their time in a bed or chair. Due to their inability to change positions, the insufficient blood flow causes blood clots in areas that are under high pressure, thus resulting in bedsore. Bedsore can develop quickly especially when there is a disorder or when the patient is injured.

Most sores heal with treatment, but some never heal completely. Steps can be taken to help prevent development of bedsore and aid healing. *Hypnos* will be one such product that helps to prevent the development of bedsore



Fig (a). Bedsore

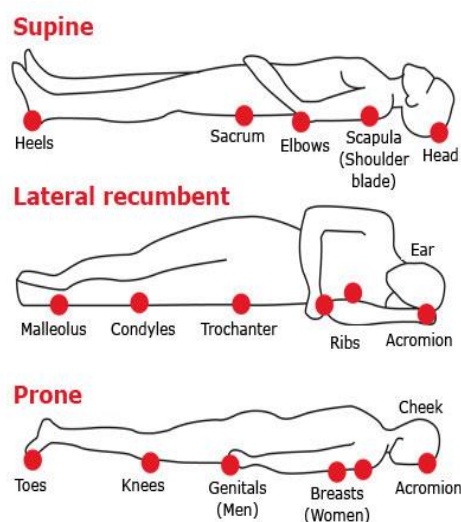


Fig (b). Stable Sleeping Positions

Literature Survey:

Background:

Bedsore are caused by pressure against the skin that limits blood flow to the skin. Other factors related to limited mobility can make the skin vulnerable to damage and contribute to the development of pressure sores. Three primary contributing factors for bedsore are:

- **Pressure:** Constant pressure on any part of our body can lessen the blood flow to tissues. Blood flow is essential to delivering oxygen and other nutrients to tissues. Without these essential nutrients, skin and nearby tissues are damaged and might eventually die. 10 kPa causes tissue death. For people with limited mobility, such pressure tends to occur in the pressure points (areas that aren't well-padded with muscle or fat and that lie over a bone, such as the spine, tailbone, shoulder blades, hips, heels and elbows).
- **Friction:** Friction exists when the skin rubs against clothing or bedding. It can make fragile skin more vulnerable to injury, especially if the skin is moist.
- **Shear:** Shear occurs when two surfaces move in the opposite direction. For example, when a bed is elevated at the head, one can slide down in bed. As the tailbone moves down, the skin over the bone might stay in place — essentially pulling in the opposite direction.

For those who use a wheelchair, pressure sores often occur on skin over the following sites:

- Tailbone or buttocks
- Shoulder blades and spine
- Backs of arms and legs where they rest against the chair

For people who are confined to a bed, common sites include the following:

- Back or sides of head
- Shoulder blades
- Hip or lower back of tailbone
- Heels, ankles and skin behind the knees

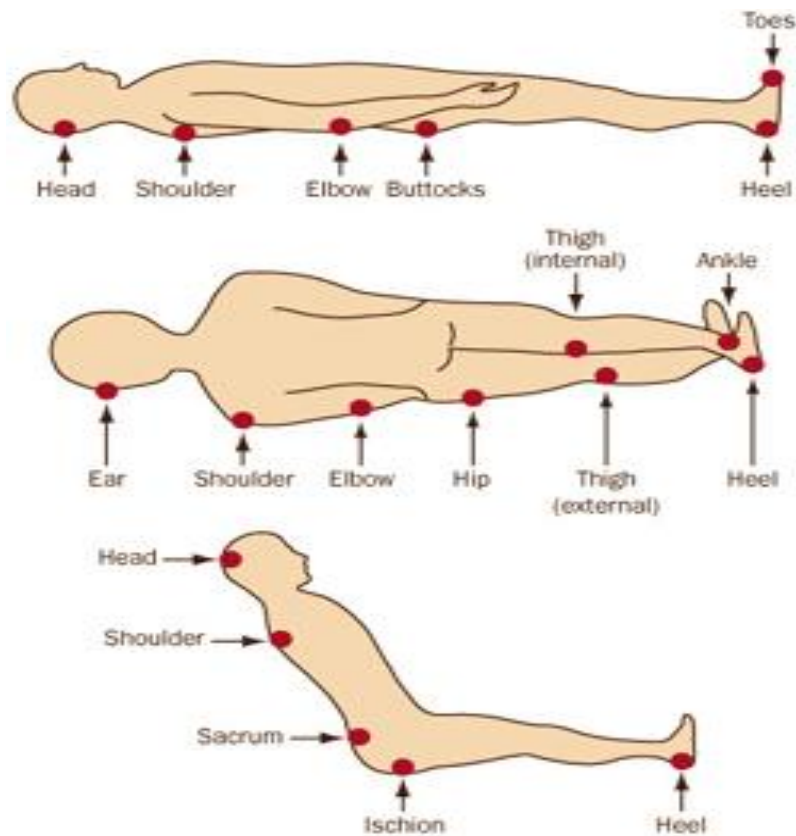


Fig (c). Locations of Bedsores

a. Risk factors

People are at risk of developing pressure sores if they have difficulty moving and are unable to easily change position while seated or in bed. Risk factors include:

- **Immobility.** This might be due to poor health, spinal cord injury and other causes.
- **Lack of sensory perception.** Spinal cord injuries, neurological disorders and other conditions can result in a loss of sensation. An inability to feel pain or discomfort can result in not being aware of warning signs and the need to change position.
- **Poor nutrition and hydration.** People need enough fluids, calories, protein, vitamins and minerals in their daily diet to maintain healthy skin and prevent the breakdown of tissues.
- **Medical conditions affecting blood flow.** Health problems that can affect blood flow, such as diabetes and vascular disease, increase the risk of tissue damage.

b. Complications

Complications of pressure ulcers, some life-threatening, include:

- **Cellulitis.** Cellulitis is an infection of the skin and connected soft tissues. It can cause warmth, redness and swelling of the affected area. People with nerve damage often do not feel pain in the area affected by cellulitis.
- **Bone and joint infections.** An infection from a pressure sore can burrow into joints and bones. Joint infections (septic arthritis) can damage cartilage and tissue. Bone infections (osteomyelitis) can reduce the function of joints and limbs.
- **Cancer.** Long-term, non-healing wounds (Marjolin's ulcers) can develop into a type of squamous cell carcinoma
- **Sepsis.** Rarely, a skin ulcer leads to sepsis.

c. Symptoms

Warning signs of pressure ulcers are:

- Unusual changes in skin colour or texture
- Swelling
- Pus-like draining
- An area of skin that feels cooler or warmer to the touch than other areas
- Tender areas

Bedsore fall into one of several stages based on their depth, severity and other characteristics. The degree of skin and tissue damage ranges from red, unbroken skin to a deep injury involving muscle and bone.

d. Prevention

The optimum nursing condition was determined, i.e. *kinetic nursing*, which is by definition: the automatic and continuous turning of a patient equally from side to side, in a given posture, through a maximum excursion of 124° at a minimum rate of 124° in 4.5 minutes. Bedsore can be prevented by frequently repositioning the patient to avoid stress on the skin. Other strategies include taking good care of your skin, maintaining good nutrition and fluid intake, quitting smoking, managing stress, and exercising daily.

e. Treatment

- *Negative pressure wound therapy*

Also known as vacuum-assisted therapy, this procedure involves the attachment of a suction tube to the bed sore. The tube draws moisture from the ulcer, drastically improving the healing time and reducing the risk of infection. Wounds heal within around 6 weeks at half the cost of surgery.

- *Surgery*

Some bedsores may become so severe that surgical intervention is necessary. Surgery aims to clean the sore, treat or prevent infection, reduce fluid loss, and lower the risk of further complications. A pad of muscle, skin, or other tissue from the patient's body is used to cover the wound and cushion the affected bone. This is known as flap reconstruction.

f. Stages of bedsores:

Pressure sores develop in four stages.

1. The skin will look red and feel warm to the touch. It may be itchy.
2. There may be a painful open sore or a blister, with discoloured skin around it.
3. A crater-like appearance develops, due to tissue damage below the skin's surface.
4. Severe damage to skin and tissue, possibly with infection. Muscles, bones, and tendons may be visible.

An infected sore takes longer to heal, and the infection can spread elsewhere in the body.

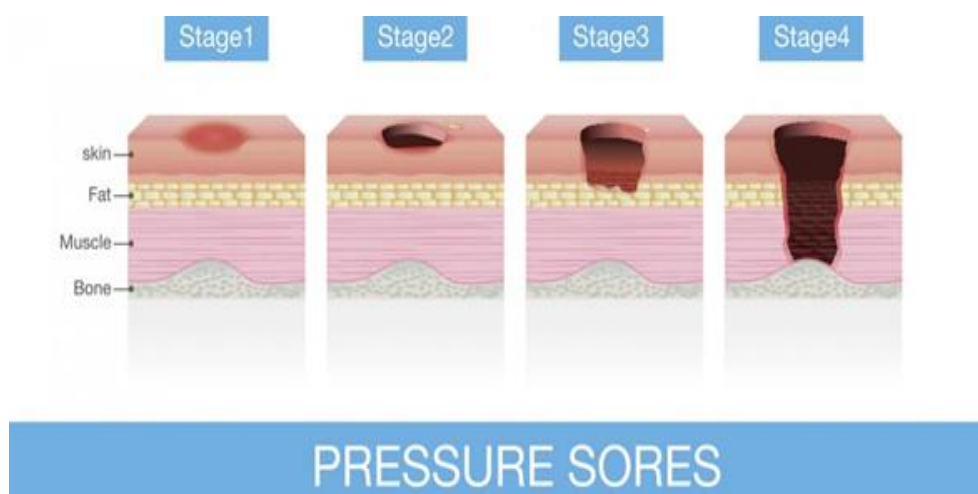


Fig (d). Stages of Bedsores

g. Survey:

A survey regarding bed sores was conducted amongst doctors of various specializations.

Results of the survey:

1. 49.4% of bed ridden patients develop bed sores
2. Average annual expenditure for treatment of bed sores is majorly between 1-10 lakh INR
3. Most common stage of severity of bedsores among permanently bed-ridden patients is *stage 3*.
4. The methods used to prevent bed sores are:
 - Changing positions (most common)
 - Pressure relieving mattress
 - Air mattress
 - Soft beds
 - Creams and skin smoothening agents

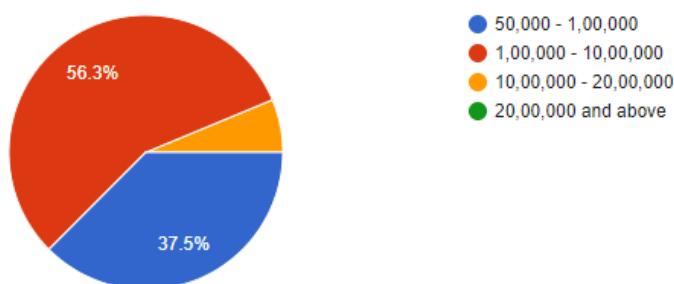


Fig (e). Average annual expenditure for treatment

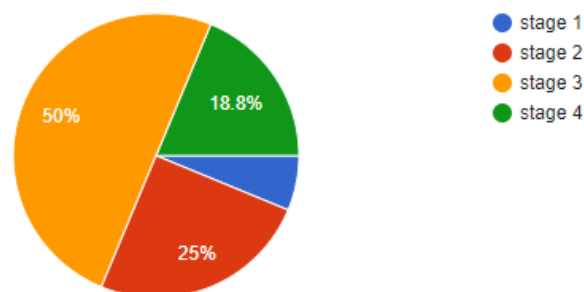


Fig (f). Common stage of severity of bedsores

Problem:

The nurses or caretakers are supposed to change the positions, to shift the patient's pressure points periodically. This is a cumbersome and tedious process, especially in the night time. The cost heads are high when a caretaker is employed to look after the patient. Moreover, affordable beds are not available, especially in Indian market.

Problem statement:

To design an automated bed that is able to shift pressure points of a patient periodically to prevent the development of bed sores

Existing Solutions:

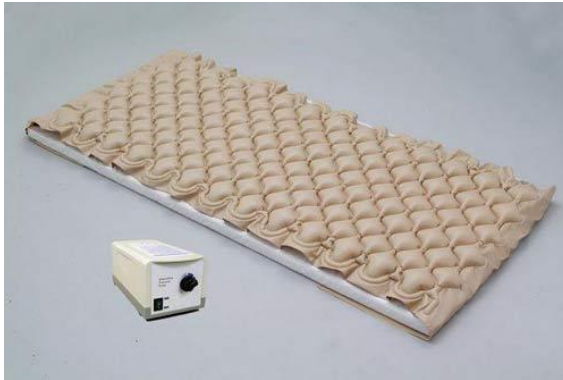


Fig (g). Air mattress



Fig (h). Roto bed

Product surveyed	Description	Cost (Rs)	Drawbacks
Pressure relieving beds	Air & water beds	1000 -1,00,000	Delays bedsores does not eliminate maintenance
Low tech devices	Air, foam, gel etc. mattress	10,000 – 10 lacs approx.	Does not eliminate bedsores
High tech devices	Alternating-pressure mattresses/overlay, Air-fluidized beds, Low-air-loss beds, Turning beds/frames	10 lacs – 50 lacs	Not affordable to common people, noisy.

Our Solution:

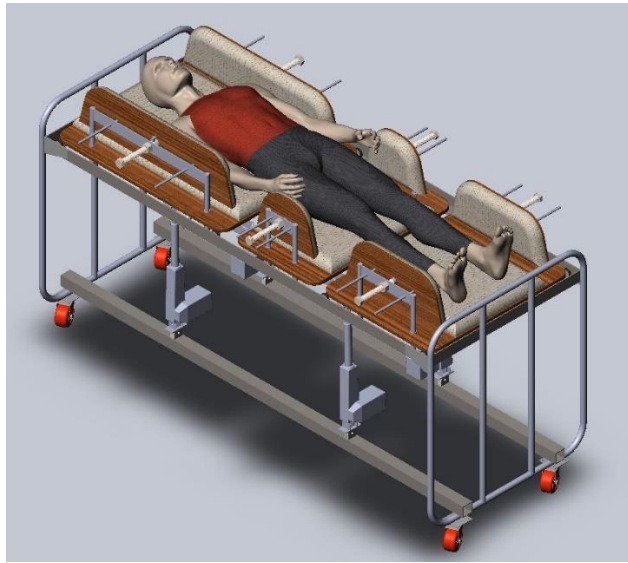


Fig (i). CAD design of *Hypnos*

Hypnos is an automated bed to prevent the development of bed sores. It is operated with 4 linear actuators and a specially designed three plate platform system. This three-plate platform system consists of three support plates made of wood and two sets of three support rods running under either side of each plate. These support plates and support rods are attached to each other by means of clamps and are rigidly held together. The actuators are in turn connected to these support rods by using universal joints, such that it has two degrees of freedom. There are latches provided which can lock the middle support plate to head and leg support plate individually. The actuators are positioned such that different combination of actuation of the four actuators give five different positions:

Sitting - In this position the torso of the body is lifted such that the person appears to be sitting. This position is used to feed the patient and to take care of the patient.

Left tilt - In this position the body is tilted to left side.

Right tilt - In this position the the body is tilted to the right side.

Trendelenburg- In this position the head is lifted up and the leg remains down so as to make a straight slanting figure; ensures normal blood flow.

Reverse-Trendelenburg – This is exactly reverse of Trendelenburg where the leg goes up and the head is down creating an exactly reverse slant.

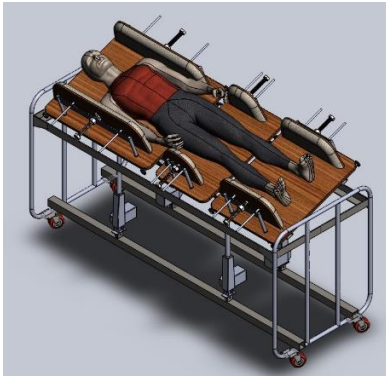


Fig (j). Right tilt



Fig (k). Left tilt

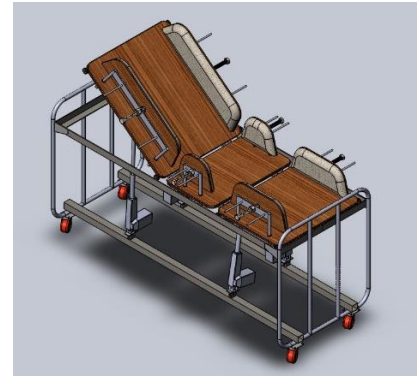


Fig (l). Sitting

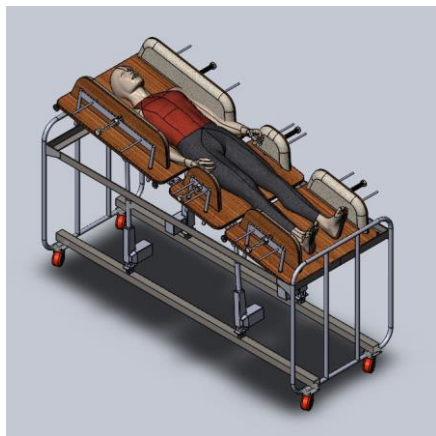


Fig (m). Trendelenburg



Fig (n). Reverse Trendelenburg

i. Working:

The supporting structure of all the components is a simple modification of a conventional cot. The head and tail stands are retained, while the plate of the conventional bed that supports the mattress is modified to a rectangular frame with 'L' cross-section, on which the mattress supporting plates rest at resting position (when all the actuators are at full retraction).

Four linear actuators are used which are positioned as shown in the sketch below and are controlled by Arduino Uno to automate actuation and to change positions periodically.

The actuators actuate two bars that lie longitudinally along the line containing actuator 1&3 and actuators 2&4. These bars consist of three segments that are connected using hinges and these hinges can be constrained using pins.

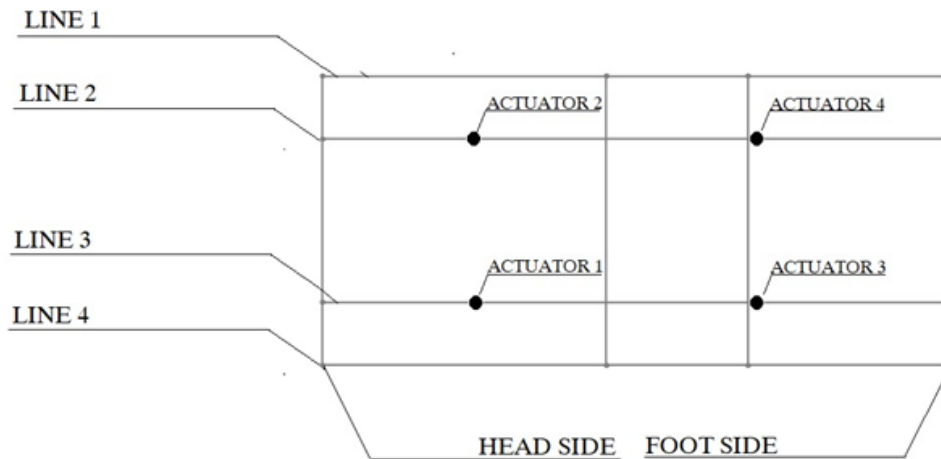


Fig (o). Schematic of *Hypnos*

The mattress rests on these plates. When the bar is moved the plate moves along with it and so does the mattress. Below is a list of combination of actuators to obtain required motion:

- 1 & 3 (with pin engaged) – tilt left
- 2 & 4 (with pin engaged)– tilt right
- 1 & 2 (with pin disengaged) – sitting up
- 3 & 4 (with pin disengaged) – knee comfort
- 1 & 2 (with pin engaged)—Trendelenburg head up
- 3 & 4 (with pin engaged) ---Trendelenburg head down

ii. Workflow:

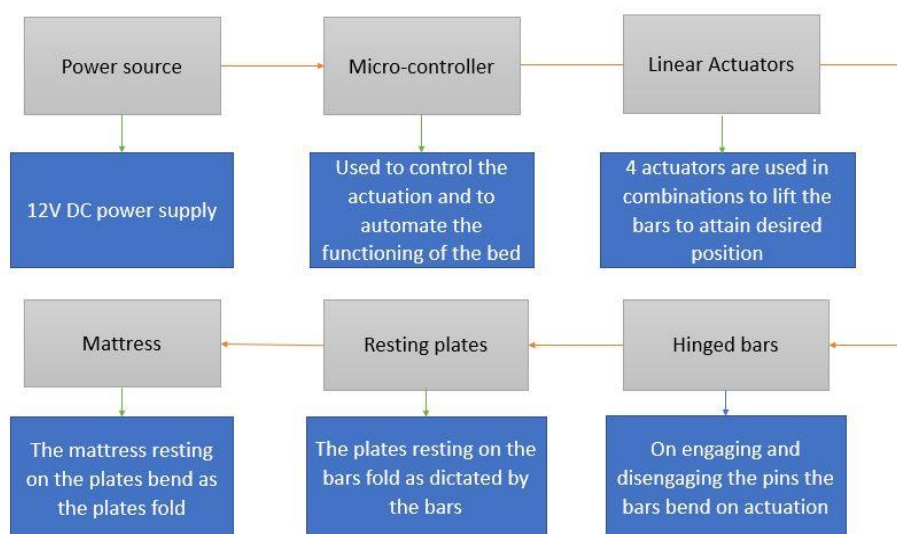


Fig (p). Flow of power in the system

iii. Electrical Control:

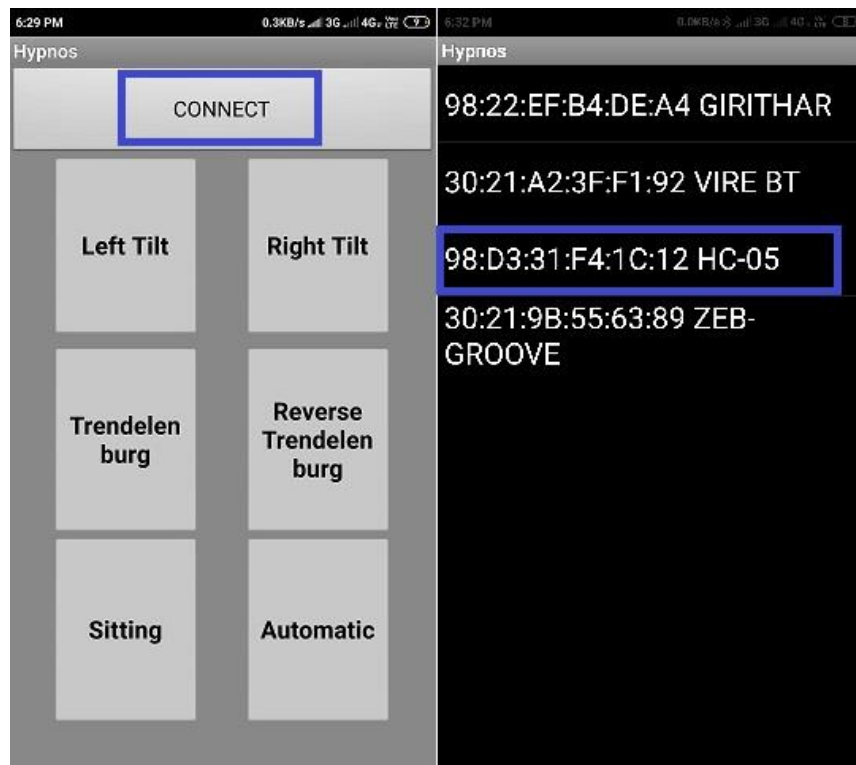


Fig (q). Screenshots of the android application

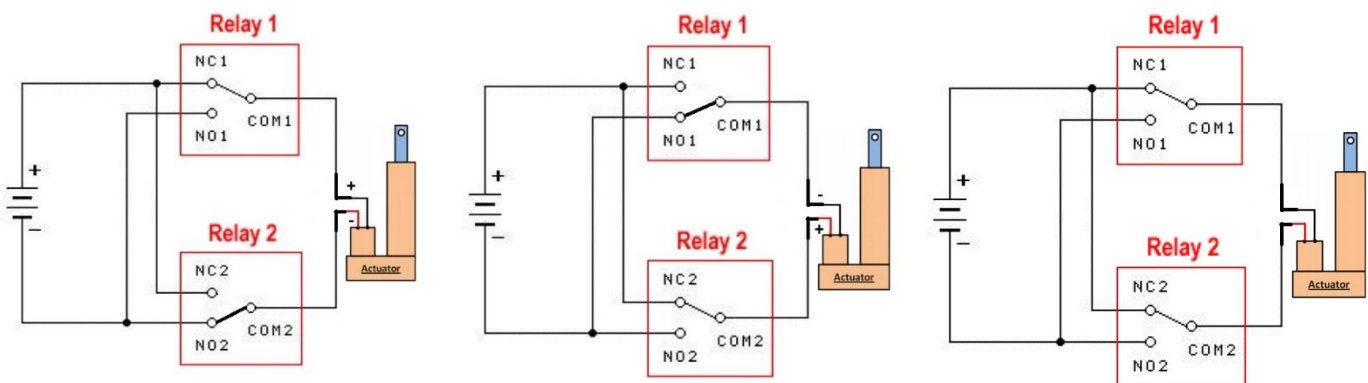


Fig (r). Circuit diagram to control linear actuator

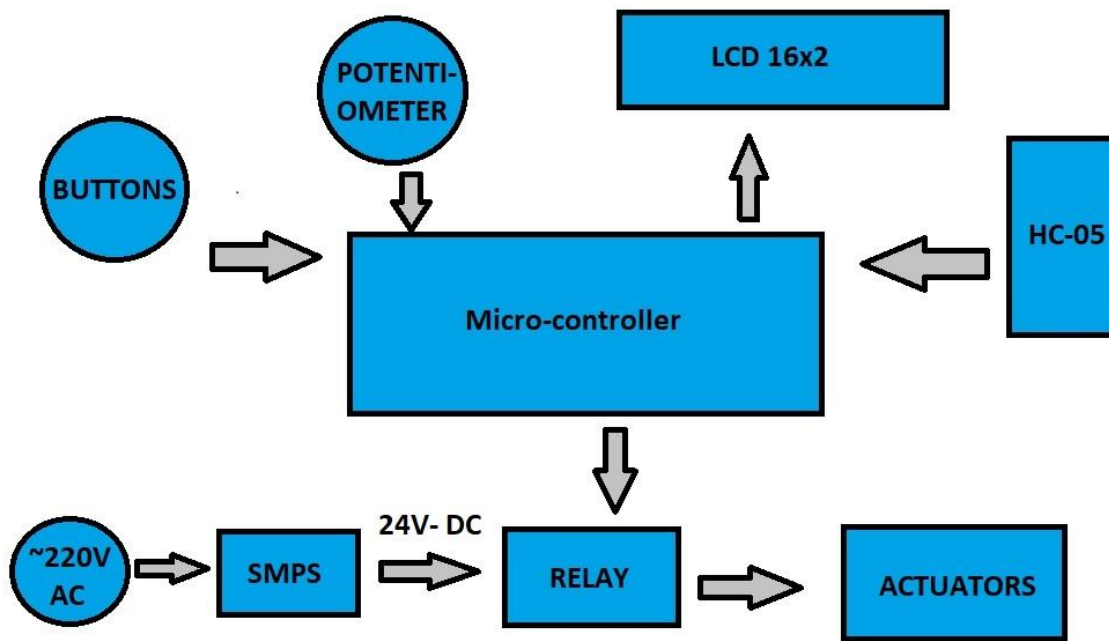


Fig (s). Signal flow

The user interface includes two buttons, a potentiometer knob and a 16 x 2 LCD display. The android application interface uses HC-05 Bluetooth module to establish a wireless connection with the microcontroller.

When the user presses the buttons or turns the potentiometer knob, the input signal is given to the micro-controller. When the user presses an option in the android application instead, the input is given to HC-05 Bluetooth module which in turn sends the signal to the micro-controller.

A relay is an electromagnetic switch. It is used in application to turn on and off a circuit by low power signal, or where several circuits must be controlled by one signal.

Micro-controller cannot provide enough power supply to operate the linear actuators. So, relays are used to connect the batteries to the linear actuators. The relays are operated by the low power signal from the micro-controller.

iv. Components:

Component	Description
Side frames	2 side frames made of mild steel pipe of diameter 30mm, 2mm thick
Bottom support rods	2 hollow mild steel square pipes (80x80 mm) of 2100 mm length 5 mm thick, welded to the side frames
Top support rods	3 pairs of mild steel hollow square pipes (80x80 mm), 5mm thick for torso (900mm), middle (450mm) and leg portion (600mm)
Support plates	3 wooden plates for each pair of support rods (20mm thick & 785mm wide)
L frame	5 mm thick mild steel frame on which the plates sit
Universal joints	8 chromoly universal joints to ensure 2 DOF for the actuators
Latches	Provided to lock the middle plate with the top and bottom plates
Side flaps	Adjustable Foam side flaps provided to prevent sliding of the patient
Castor wheels	Load bearing nylon castor wheels
Mattress	Multi density articulated mattress made of different grades of polyurethane

v. Analysis:

The load bearing components of Hypnos are analysed for failure and to find the factor of safety in Ansys 18.1. On applying a load of 200N per actuator at the points of interest the following stress variations and deformations were observed. The deformation is not more than 2 mm in the exaggerated scale.

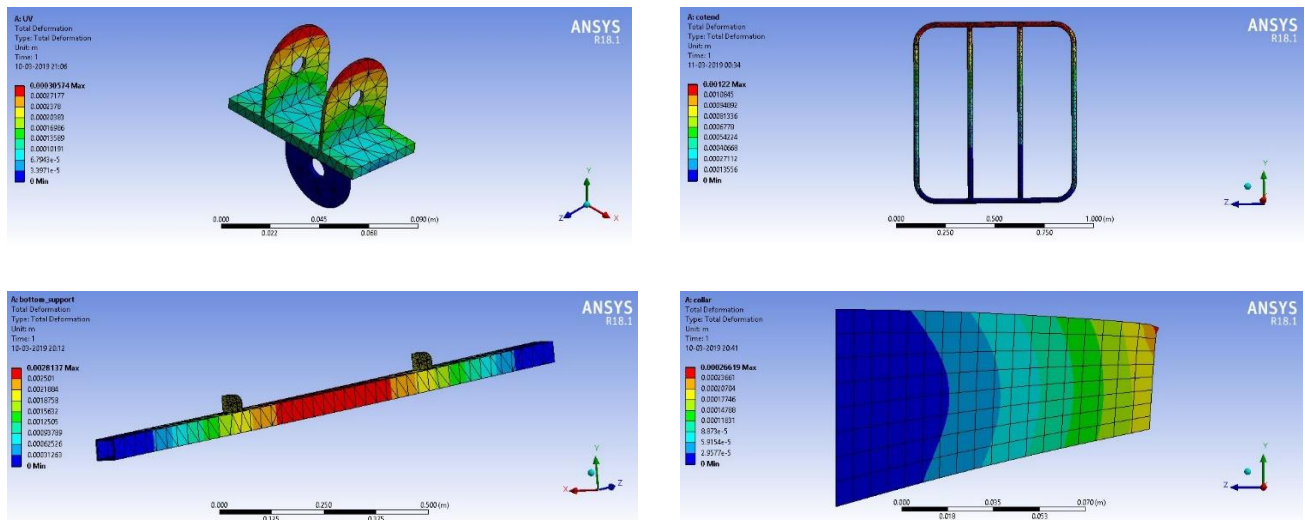


Fig (t). Deformation in components

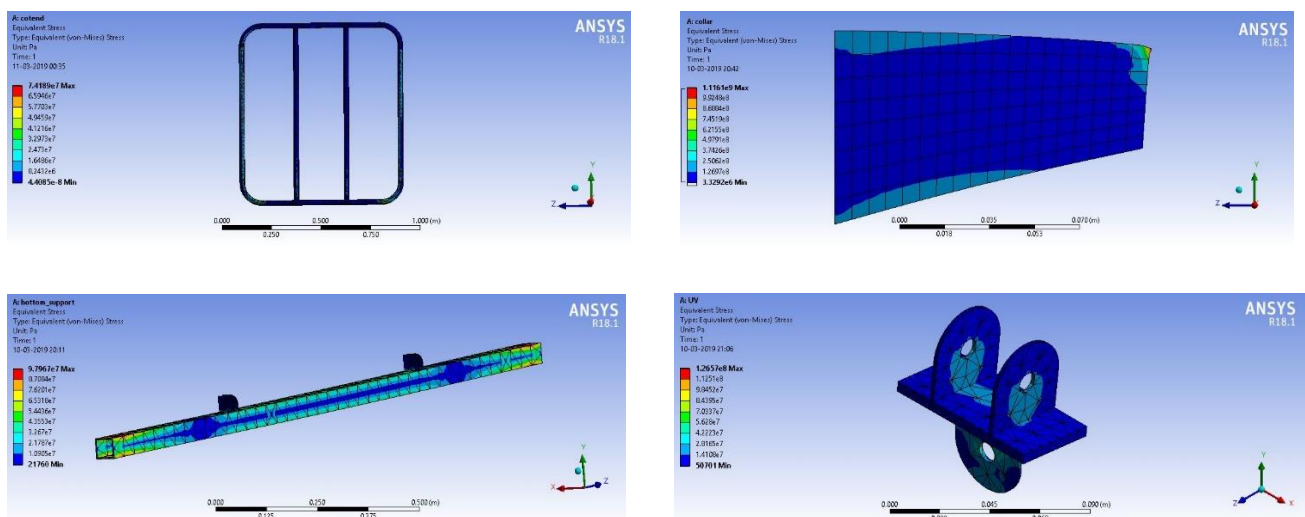


Fig (u). Stress distribution in components

vi. Innovation:

To impose the innovativeness of our product the existing solutions must be analysed. Most of the existing products employ the same approaches i.e. either distribute the pressure throughout the body or to shift the pressure points frequently. The first principle, which is aimed only to delay occurrence of bed sores, employs different types of pressure relief mattress such as memory foam, beds filled with air, gel, water. The second principle, which is aimed to prevent the development of bed sores, the solutions available are very expensive. For instance, Invacare 5310IVC costs 20,00,000 INR whereas our product is estimated to cost 30,000INR

Our solution provides a product that is automatic, easily accessible and very much affordable in comparison to the existing ones. By attaining different positions such as tilting clockwise and counter clockwise by 30 degrees; Trendelenburg and Reverse Trendelenburg positions; the bed will be converted into specific orientations that would allow the person to be in comfortable positions. One of the prominent features is that the bed permits the patient to sit during feeding without assistance simultaneously accounting for knee comfort as well.

vii. Impact:

In most cases of medical conditions like paralysis or coma wherein the patient is bedridden, either the nurse or one of their family members is obliged to frequently shift the position of the patient for uniform blood flow. This process becomes cumbersome and hectic and also becomes expensive considering the fact that the caretaker must be paid. None of the existing products pays itself in this regard. With this notion *Hypnos* has been designed such that it is automated, thus avoiding a person to look after the patient throughout the night. The following data shows the possible expenditure in the absence of a product like *Hypnos*:

Stage IV Pressure Ulcer– Skin flap surgery is necessary in cases of Stage IV pressure ulcers. When the skin has broken down to this level, the chances of recurrence are statistically probable. The average cost of muscle flap surgery is 44,00,000 INR not including time lost from missing work or school.

Pneumonia– The presence of any infectious complication, pneumonia for example, can result in re-admission and increased length of stay and charges per patient; which can be as high as 30,00,000 INR per incident.

Personal Care Attendant– “Annual” costs are approximately 3,00,000 INR based on an 8-hour night shift at Rs.100 per hour. Hourly rates differ from state-to-state, and could be higher if skilled nursing care is warranted.

Provided the fact that in India, paralysis prevails among 0.89% of the population i.e., for approximately 9,585,635 people, *Hypnos* will be a perfect product for the Indian society.

viii. Salient Features:

- **Ensures comfort.** Activities like cleaning the patient, carrying out physiotherapy, etc. can be performed easily.
- **Compatibility.** The adjustable side flaps make the bed compatible to different sizes of patients.
- **User friendly interface.** The interface is simple and easy to understand. It doesn't need any specific skill to operate the device.
- **Fully automated.** It reduces human labour (especially at night). Hence, it enhances the mental and physical health of patient and caretakers.
- **100-fold cost reduction.** The existing solutions range in cost between 25-50 lakh rupees. While the unit cost of production of *Hypnos* is 37,000 INR.
- **Multiple positions and states.** Five different positions namely Trendelenburg, Reverse Trendelenburg, Right tilt, Left tilt and sitting positions are achieved.
- **100% prevention of bedsores.**

ix. Technical report:

	length	cog		cogl		relative mass
head	38.9	0.598	vertex	23.2622	64.4378	6.9
trunk	48.8	0.449	supersternal	21.9112	26.8888	43.46
upper arm	30.2	0.577	shoulder	17.4254	31.3746	5.42
forearm	26.9	0.457	elbow	12.2933	6.3067	3.24
hand	21	0.79	wrist	16.59	-24.89	1.22
thigh	46	0.41	hip	18.86	-18.86	28.32
shank	45	0.446	knee	20.07	-66.07	8.66
foot	9.4	0.442	heel	4.1548	-95.1548	2.74
						99.96

Fig (v). Centre of gravity of body parts

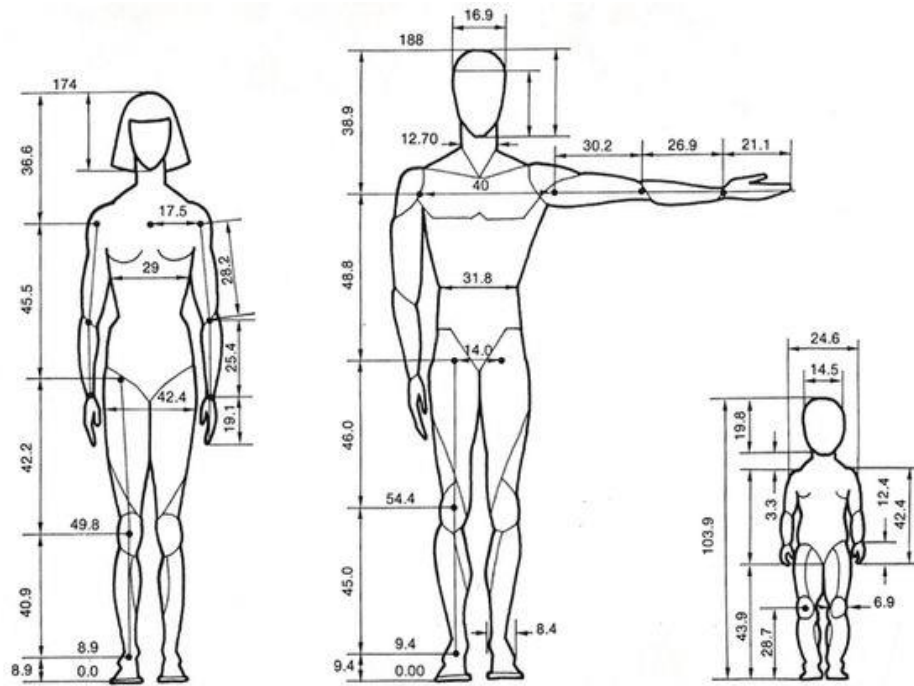


Fig (w). Average body ratio

x. Dimensions:

From the values mentioned in the table above, the dimensions for the design have been fixed:

Width of bed	: 3 ft
Length of bed	: 6 ft 3 inches
Width of torso	: 1.5 ft
Clearance of bed from ground	: 80 cm
Width of flap 1	: 0.65 ft
Width of flap 2	: 1.7 ft
Width of flap 3	: 0.65 ft
Length of portion 1	: 90 cm
Length of portion 2	: 45 cm
Length of portion 3	: 60 cm
Actuator stroke length	: 30 cm
Stroke speed	: 4 mm/s

xi. Cost analysis:

S.No	Component	Cost (Rs)
1.	Actuators	15000
2.	MS pipes, plates, rods	14850
3.	Wooden boards	3000
4	Fasteners	1000
5.	Castor wheels	500
6.	Electronics equipment	2000
7.	Fabrication	2400
	Total	37,750

xii. Scope of Improvement:

- Actuation control by conscious patients
- Retractable side flaps to make it easy to place and shift the patient from the bed
- Accommodation of other medical facilities in the structure
- Developing into an aesthetic product
- Feedback based control system

References:

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- Microair – https://www.youtube.com/watch?v=73KfVF10J_U&feature=youtu.be
- Toto – <https://vimeo.com/136114242>
- Alphacare APM2 Lateral Turning Mattress – <https://www.youtube.com/watch?v=G0Z3DJXD7WQ>
- Flex bed - [Video Link](#)
- Invacare® G-Series Bed - https://www.youtube.com/watch?v=4mY_ObsMaN8&feature=youtu.be
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- Bedsore incidence - <https://indianexpress.com/article/cities/chandigarh/bedsore-incidence-highest-among-those-admitted-to-icuc-pgi-study/>
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- Universal joint - <https://www.youtube.com/watch?v=4sVl4bk-NDs>
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- Polyurethane compressibility - <https://www.youtube.com/watch?v=DDgYQ09Hms0>