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Research Article

Design and Development of Lateral Tilting Mechanical Bed to Reduce Pressure Ulcers

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Abstract

Bedridden patients are more likely to develop Pressure Ulcers (PUs) due to prolonged sleeping in supine posture on hospital bed. Pressure Ulcer is developed due to functional imbalance of human body due to gravitational pull of human organs and mechanical loading of human tissues that reduces oxygen supply and damage the tissue. To prevent the Pressure Ulcers, high technology beds, Support surfaces and frequent repositioning of patients is done frequently. Assisted or manual repositioning of bedridden at hospitals or at home increases incidence of back pain among hospital staff, and which leads to increased skin damage of bedridden. This is due to friction and shearing forces during assisted turning. Lateral tilting bed enables bedridden patients to reposition easily and frequently, that reduces external forces like shear and friction as well as reduces the effort and incidence of back pain among caretaker by assisted turning. Thus, reduces the risk of Pressure Ulcers. This paper presents the work carried out by the author in the field of design and fabrication of hospital bed to reduce pressure ulcer.

Keywords: *Pressure Ulcers (PUs); Bedridden; Hospital Bed*

Introduction

PUs on bony prominences affects almost all bedridden patients and is a major concern in healthcare system. These are localized injuries to intact skin mostly caused by pressure or pressure in combination with shear and frictional stresses. Some additional factors that contribute to this cause are prolonged sleeping behaviour i.e. immobility and malnutrition [1].

PUs cannot be avoided but they can be prevented. Once developed, it leads to acute health condition and results in costly medical remedies. If neglected, it becomes worst, painful situation for patient and requires months or even years to recover. Estimated cost for treating the PU currently in health care system is more than Rs. 84 billion annually [2]. It was observed that cost of treating single PU is about Rs. 3,022,600 for stage III whereas for stage IV ulcer, it can reach up to Rs 4,900,000 [3].

To prevent the PU, alleviating pressure and frequent repositioning of patients is most effective practice. High technology beds, special support surfaces are available to prevent PUs, but these products are very costly and cannot be availed by patients from remote areas. Also assisted or manual repositioning of bedridden patients at hospitals or at home increases incidence of back pain among hospital staff, and there may be chances of skin damage of bedridden patient due to friction and shearing forces developed when patient is pulled or pushed against the support surface. Lateral tilting bed enables bedridden patients to reposition easily and frequently, that reduces external forces like shear and friction as well as reduces the effort and incidence of back pain among caretaker by assisted turning.

Objective of the Study

The objective of this research work was to solve the issue of PUs by developing lateral tilting mechanical bed. The lateral tilting mechanism used in bed will mobilize and improve the physical activity of patient, improve the blood circulation and thus reduce the pressure and other contributing factors. The motive behind this research was to develop low cost hospital bed to reduce PUs as well as to reduce care takers effort to reposition the patient.

Literature Review

PUs affects hundreds of millions of people worldwide; the severity of this problem is very high. In fact, nearly 60,000 U.S. hospital patients die from complications due to hospital-acquired PUs each year. It is estimated that 2.5 million patients are treated each year in U.S. acute-care facilities for PUs. The total cost of treatment of PUs in the United States is estimated at Rs 770 billion per year [4]. The Development of PUs is relatively common. Reported incidences of PUs in different states remain one of the most neglected aspects of health-care provision in India and identifying their associated risk factors at an early stage may go a long way in preventing their occurrence [5].

Major contributing factors include mechanical loading (shear, friction and pressure), mobility, time, nutrition, microclimates like moisture and temperature.

Literature review conducted on previous studies carried out in the relevant area is presented below.

For patients who are at high risk of PU development positioning and mobilizing is the key priority. At least, sitting should be encouraged where pressure on ulcer can be managed. It is also advised to mobilize the patient and avoid bed rest. Positioning the bedridden patient for the prevention of PU is very challenging job [6].

A pilot study conducted on 20 adult quadriplegic patients to identify the effect of body position and mattress type on interface pressure to reduce PU and found that lower positions produce lower interface pressure and pressure relieving mattresses reduces interface pressure more quickly than pressure reducing mattresses [7].

A randomized control trial was conducted by Moore Z and Seamus C [8] on 213 participants during 2006 - 2009 to determine the effect of the 30° repositioning technique on the incidence of PUs compared with usual PU prevention practices. It was concluded that the incidence of PUs was 3% in the experimental group and 11% in the control group. Also repositioning patients at risk of PUs every three hours at night using the 30° tilt reduces the incidence of PUs more than usual care.

A study was reported by Vanderwee K., *et al.* [9] for finding effectiveness of repositioning patients lying on a pressure-reducing mattress alternately for 2 hours in a lateral position and 4 hours in a supine position reduces the incidence of PUs in comparison with repositioning every 4 hours. It was concluded that more frequent repositioning on a pressure-reducing mattress is not significant to reduce PU and hence cannot be considered as an effective preventive measure.

Managing pressure, friction and shear forces is very much essential in PU prevention method. It requires an interdisciplinary team approach, while considering treatment plan. Focus should be on mobilizing the patient, use of specialized mattresses, and use of multifunctional bed to reduce the risk. Regardless of these support surfaces and tools, it is important that caretaker must be knowledgeable to handle and maintain these equipments [10].

Frequent positioning of patient on bed is carried out either manually or by modern motorized hospital beds. Literature based on various methods of reposition and patents on hospital beds to reduce PUs are summarized below.

Hampton C [11] conducted the first experimental trial in UK on motorized profile bed frame and identified positive impact of these beds as compared to standard hospital beds to reduce PUs and implementation of hospital lifting policies.

Keogh A and Dealey C [12] studied the effect of motorized profiling bed frames on PUs incidences. They found that after using motorized beds patients those who are at high risk of PUs development on standard hospital beds get benefited.

Williams C [13] reported in his study stated that the use of knee break and other features of electric bed frames can reduce the PUs at sacral location.

Gray., *et al.* [14] conducted study of evaluation of motorized beds designed for nursing homes. Through set of questionnaires he evaluated staff opinions on these new eclectic beds in terms of caring for patient and manual handling issues. It was observed that the use of these profile beds is most beneficial than standard hospital beds for caring patients those who are bedridden and prone to PUs development.

David G., *et al.* [15] in their study of PUs reducing mattress and electric bed frames, conducted trials on 44 subjects those who had undergone cardiac surgery. Perception of subjects were observed for 6-month period and it was found that no PU development during the trial and the perception of comfort were positive.

Hata and Tadayo [16] invented anti-bedsore bed comprising of multiple expandable/ contrastable air bags of different diameters placed along the bed at three different locations for repositioning the patient and also to facilitate the hospital staff for serving the patient. These air bags alternately inflate and deflate to reduce pressure and regulate the blood flow.

Soonthornkiti S and Jearanaisilawong P [17] invented the design which employs a change in pressure point mechanism by vertical movement of partitioned cushion by using actuators operated by centrally designed custom-made control board.

Yanin [18] developed a bed which consist of two parts and operated to move the bed upward and downward at the predetermined time by using a timer. The movement of the two parts result in the shifting of the patient's weight pressed against the bed. When one part moves downward below other part, the later supports the patient's entire weight, and when second moves downward below first part, then previous supports the patient's entire weight. The points where the weight is supported on first and second parts are different depending on the cushion arrangements.

Atul B Andhare and Anil M Onkar [19] from their study reported that there is urgent need to design and fabricate a new bed for critically ill patients. This bed should be designed as a single unit with multiple facilities like multiple tilting, commode attachment, using the following design criteria:

1. Design of bed should be simple and easy to operate
2. Movement of patient should be minimum
3. It should provide additional facility.
4. It should reduce the effort of work/assistance required to manage bedridden patients.

Methodology

Following methodology was used:

1. Survey of hospitals, nursing homes and stakeholders was carried out to define the problem.
2. Various present practices described in the literature and their merits/demerits were studied.

3. Requirements of the product along with sizes and arrangements of components were finalized.
4. Identification of possible mechanisms and selection of appropriate mechanisms was done.
5. Analysis and synthesis of selected mechanisms was performed.
6. Feasibility study of designed mechanism was carried out.
7. Sizes of different parts of bed were decided by anthropometric data and standard design procedure.
8. 3D model of the bed was prepared for various degrees of freedom and motions.
9. Final model was then fabricated and tested for load, desired posture and movements.

Data collection/survey

A survey was conducted to identify the problems associated with pressure ulcers. A questionnaire was designed, and the survey was conducted amongst doctors, care takers including nurses and ward boys. Responses were collected from 42 respondents including patients, doctors, nursing staff and family members of patients.

From the data collected through the survey, it was observed that 30 respondents (92%) confirmed requirement of special bed and 12 respondents (8%) suggested bed with multiple tilting mechanism.

Expectations of the respondents are listed below:

1. Reduction in effort of work/assistance required to patients
2. Bed with provision of multiple tilting mechanism
3. Bed with head and leg elevation for sitting posture
4. Bed should be Simple and easy for operation
5. Bed should be low cost, in the range of Rs. 20,000/- to 30,000/-

Thus, need of a special bed for bedridden patients to reduce pressure ulcer was confirmed and based on the expectations of the people surveyed design requirements were finalized and new product design ideas were initiated. Before initiation of new design some attempts described in the literature were studied and few initial ideas were generated.

Result and Discussion

Idea generation and selection of new bed design

Based on the product specifications decided after survey, various ideas of mechanisms for providing motions to head elevation, leg-rest and lateral tilting were generated.

Parameters to be considered for design of bed:

- The bed is to be designed on the basis of 95th percentile height and weight of the human body.
- The designed bed should have multiple adjustments so as to handle the patient with ease.
- The material used for fabrication of the bed should also be available at low cost and also simple mechanisms should be used to get different motions and adjustments.
- Design must be user friendly.
- Safety of patient and care takers is of utmost importance.

By considering above parameters few ideas were generated as shown in figure 1.

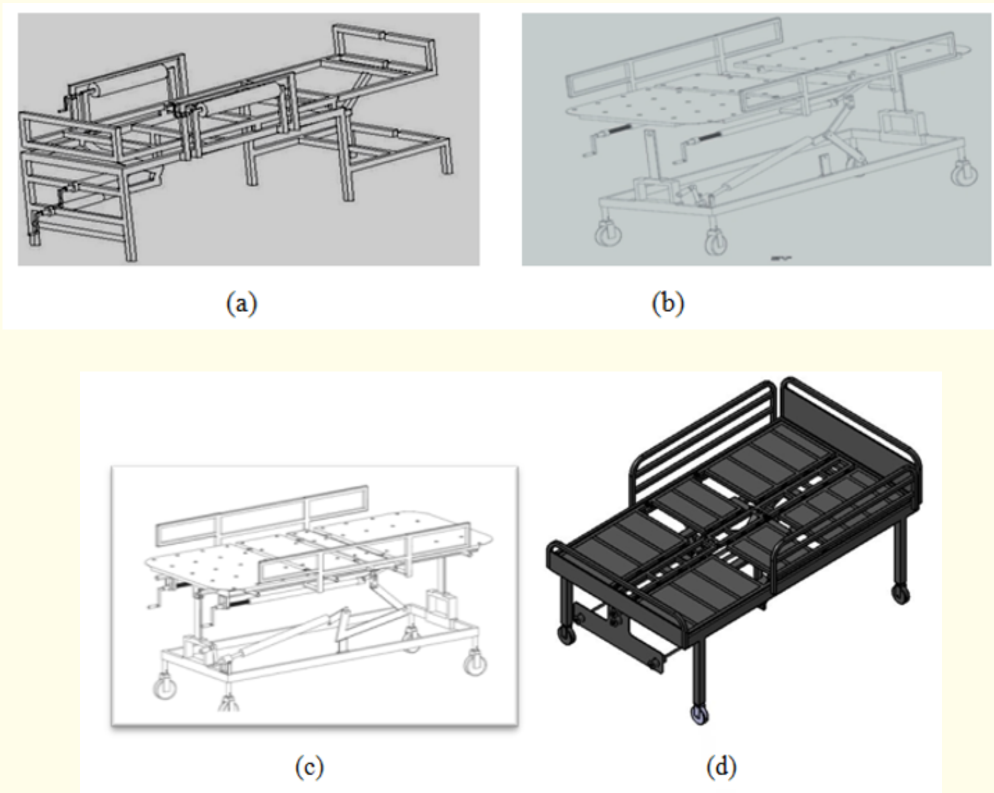


Figure 1: *Ideas generated for bed.*

Repositioning the patients with ease was first objective, accordingly bed was designed with roller mechanism in which a curtain was passed through these two rollers and by rotating the rollers tilting action can be performed. The drawback of this was that while lifting the patient and rotating the roller efforts required are very high. Also, there is no relief in pressure exerted on the bottom part of the patient. Thus, the purpose is not served.

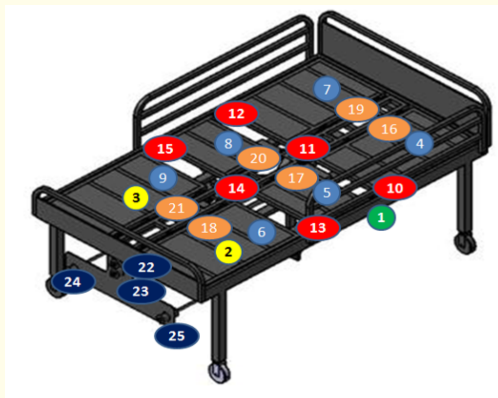
Repositioning the patient using roller mechanism is replaced by simple linkage mechanism. In which main frame was tilted by using 'V' shape linkage mechanism as shown figure 1b. But in this mechanism, there was problem of sudden jerk while operating the mechanism. Few modifications were carried out in it and the ‘V’ shape link was replaced by simple link mechanism for tilting the bed as shown in figure 1c.

After discussing with doctors and experts few more modifications were suggested, and the current model was finalized as shown in figure 1d. After finalizing the idea for making prototype 3D CAD model was prepared in CATIA.

CAD modeling and fabrication of final design

After selecting the final design and collecting the anthropometric data next step was to prepare CAD model and fabrication of prototype. CATIA V5R20 CAD software was used to design the different parts and mechanisms of the bed.

Final design of bed consists of base structural frame with four legs on which main frame is supported. This main frame is divided into nine sub frames. Three frames at the centre are supported by lower supporting rods and other six frames are on either side of these middle frames which are further supported by base structural frame. All these frames are hinged together by nut and screw for tilting. The upper three sub frames for head/ back elevation, lower three sub frames for leg mobility and six side frames three on each side are for lateral tilting. An extra supporting frame is fixed to upper three frames to bear major load of patient. Upper middle frame is connected to head/back elevation mechanism which is operated by lead screw in combination with three arm pivot links. All side frames are connected to lateral tilting mechanism operated with the help of pair of bevel gears and lead screw. Lower middle frame is operated for leg mobility with help of similar mechanism of head/ elevation. The final 3D CAD model with detailed drawings of main components can be seen in figure 2 to 5.



Sr. No.	Parts
1	Main frame
2	Right Side frame
3	Left Side frame
4,5,6	Sub frames (4,5,6) of right side frame (2)
7,8,9	Sub frames (7,8,9) of Left side frame (3)
10,11,12	Hinges for Head board elevation
13,14,15	Hinges for Leg board elevation
16,17,18	Hinges for right side lateral tilting
19,20,21	Hinges for left side lateral tilting
22	Lead screw arrangement for head elevation
23	Lead screw arrangement for Leg elevation
24,25	Lead screw arrangement for left and right lateral tilting respectively

Figure 2: *Final 3D model of bed.*

Lateral tilting mechanism

Lateral tilting provision in hospital beds is the recent trend; purpose is to reposition the patient to get relief from skin bed interface pressure and for some physical activities. This provision is currently being addressed by foreign countries like America and Japan but is still is in infant stage in some other countries. This lateral tilting mechanism is only available in electrically operated beds. Purchasing cost and maintenance cost are major problems of these electrically operated beds. Also, problem with these electrically operated beds are that the designer only accounted for patients' weight to lift the load and neglected the presence of visitor. If any visitor sits on the bed, electrical motors need lot of power to lift this extra load and motor quickly burns out. Some other issues like power failure, voltage fluctuations are major concern in remote areas.

Thus, initial consideration for designing the bed is addition of lateral tilting mechanism so that single nurse can reposition the patient laterally on his/her either sides. In order to keep the manufacturing costs down, newly designed bed has lateral tilting mechanism with manually cranked mechanism to reposition the patient at required angle.

Lead screws operated bevel gears on either side of central frame were used. Figure 3 and 4 show the final design of lateral tilting mechanism and its final working model respectively.

To operate lateral tilting mechanism pair f bevel gears are used with the help of lead screws as shown in figure 5.

Back and head elevation mechanism

It is constructed with a simple mechanical linkage which transfers elevating force applied to the head assembly by lead screw. Three bar pivot linkage system is used at the centre below the base frame of head section which is then connected to upper head section frame.

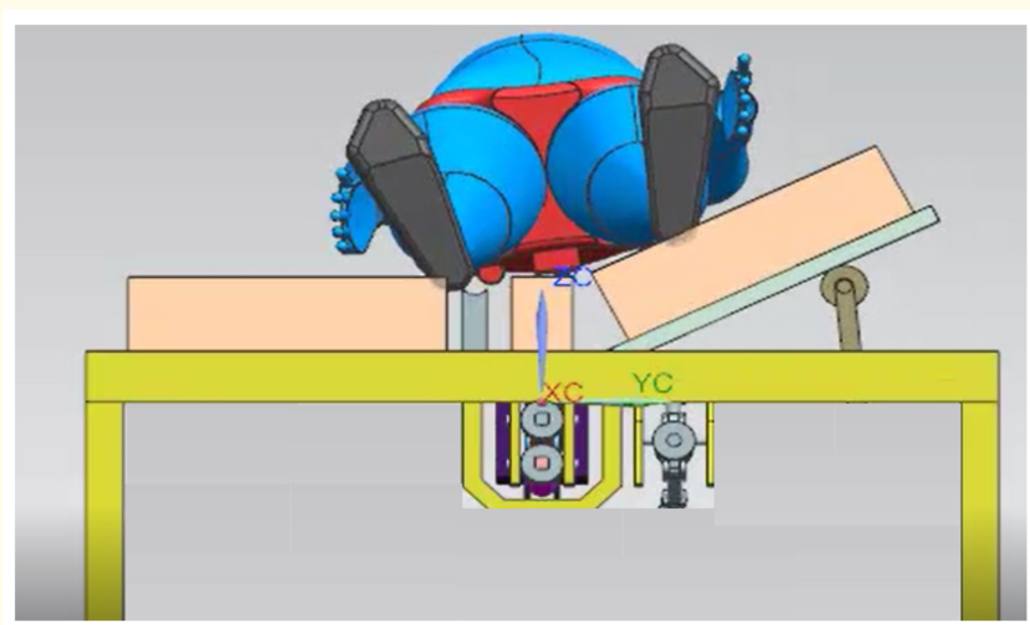


Figure 3: *3D CAD model of lateral tilting mechanism.*

Figure 4: *Lateral tilting mechanisms by using lead screw driven bevel gears.*

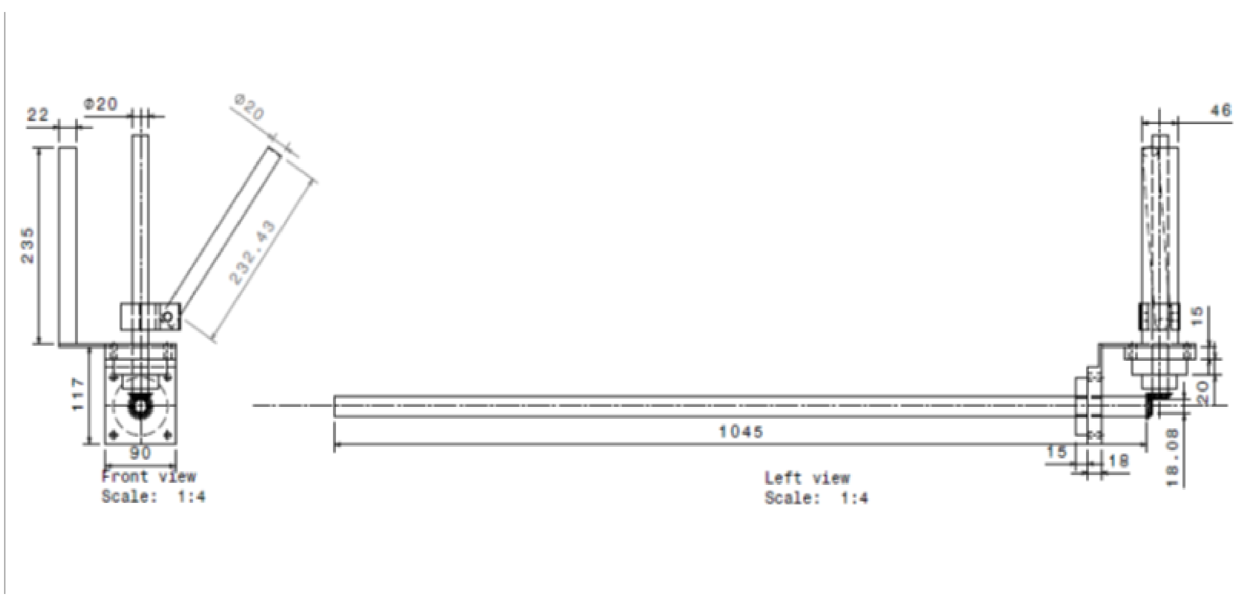


Figure 5: *Bevel gear.*

Other end of this link is connected to the lead screw with handle which lifts the load around 100 Kg. Figure 6 shows final design of head elevation mechanism.

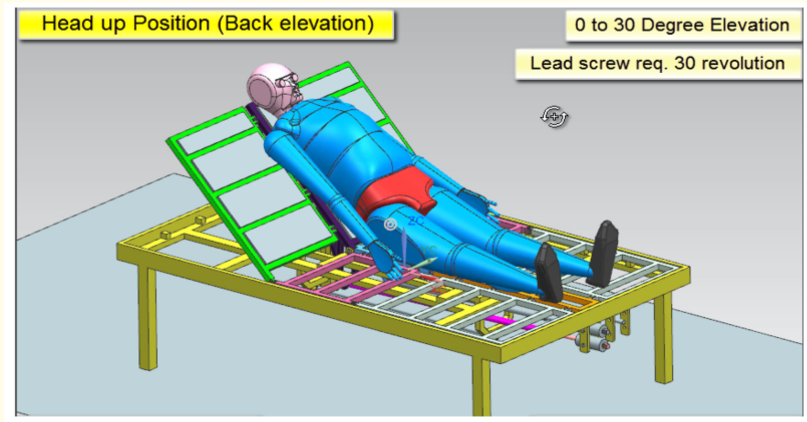


Figure 6: *Head/Back elevation mechanism.*

Leg lifting mechanism/Knee Elevation

Similar to head/back elevation mechanism, lower leg lifting mechanism is also a combination of kinematic links connected to lead screw which then can be lifted by rotating the liver attached to the lead screw as shown in figure 7.

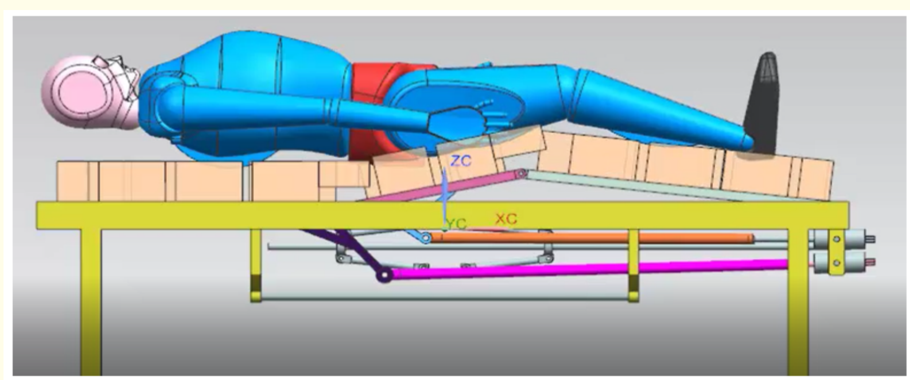


Figure 7: *Leg lifting mechanism.*

Preparation of prototyping

Prototype model was fabricated by manufacturing individual parts to the standard dimensions and assembling the parts by setting the base frame fixed and then all other operational parts around it. Then successively back elevation, leg lifting mechanism and lateral tilting mechanism was assembled to the lower base frame. Lastly all other parts like side rail, nuts, screws and bevel gears were attached to their respective parts. The complete final fabricated prototype model is shown in figure 8.

Finite element analysis of bed structure

Final geometrical model of hospital bed was carried out by using ANSYS.

Figure 8: *Final fabricated prototype of bed.*

The following assumptions and steps were carried out:

- **Modeling the problem**: In structural analysis 3D model can be prepared either in ANSYS by using modeling option or can be directly imported from CAD tool. In current research 3D model is prepared in CATIA V5R20 CAD software and imported in ANSYS. Figure 9 shows imported model in ANSYS.
- Lower part - all legs of the bed frame were immobilized
- Construction was loaded according to the schemes presented in figure 10 where in model is loaded for safe working load, transverse stability and longitudinal stability.
- **Selection of element**: Type for the Analysis: After importing of the model, it has to be converted into discrete elements which are forming the basic elements for taking the constraints and the loading conditions. This discretization is done through meshing of the model. Meshing the model generates the model in the form of small elements. So the results can be obtained to the optimum level.
- **Material properties set:** This is very important step for defining the material property like Young's modulus and Poisson's ratio which actually defines the material of the model to be analyzed in ANSYS. Structural steel with material properties Young's modulus and Poisson's ratio was set. This helps in recognizing the material for analysis (Table 1).
- **Meshing of the model:** The model imported in IGES form will appear on ANSYS window as a solid model representation. This model can be plotted in the form of areas also by plotting command. For FEM model needs to be meshed, which discreteness the entire model into fine number of elements. These elements are developed according to the element type selected. Each element possesses the property of element type. Selecting SOLID 187 element type the nodes are being formed in meshing. After meshing around 339034 nodes and 175386 elements are generated based on size and thickness of model selected. Figure 11 shows a meshed model of bed with 2060 x 1250 x 857.5 mm bounding box of length, width and height.
- **Applying the load and plotting the solution:** Three stages of solution were carried out 1 - safe working load, 2 - transverse stability and 3 - longitudinal stability. The range of analysis consisted of determination of displacements, strains and stresses developed in elements of bed model. The results were obtained and presented in table 2 as well as in the graphic form as shown in figures 12 to 20.
- **FEM analysis of the bed frame - safe working load:** In this loading scheme 1700N force was applied on the base frame for checking total deformation and stresses developed as shown in figure 12-14.
- **FEM analysis of the bed frame - transverse stability:** Transverse stability of hospital bed was analyzed by applying 1500N transversely on bed frame and results were plot in figure 15-17.

- **FEM Analysis of the Bed Frame - Longitudinal Stability:** Longitudinal stability of hospital bed was analyzed by applying 2250N longitudinally on bed frame and results were plot in figure 18-20.

Figure 9: *Geometrical model of hospital bed chosen for FEM analysis.*

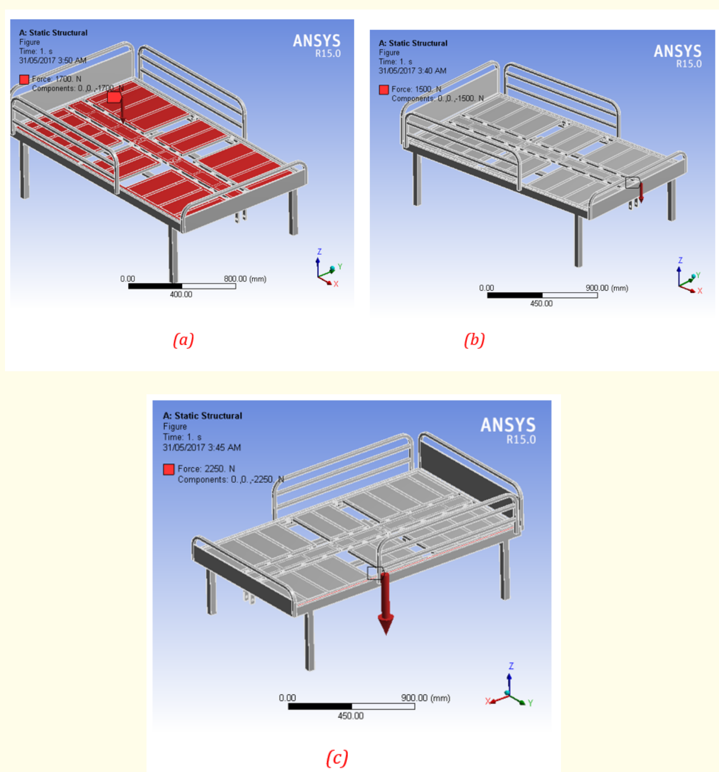


Figure 10: *Loading Scheme of Model a) Safe Working Loading b) Transverse Stability and c) Longitudinal stability.*

Material	Young's Modules	Poisson's Ratio
Structural Steel	2.e$^{+.005}$ MPa	0.3

Table 1: *Material properties.*

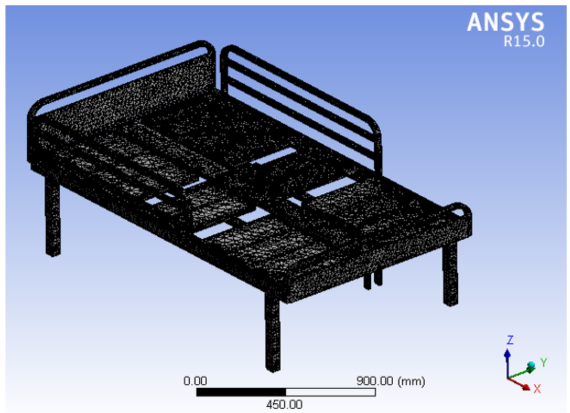


Figure 11: *Fine meshed model of bed.*

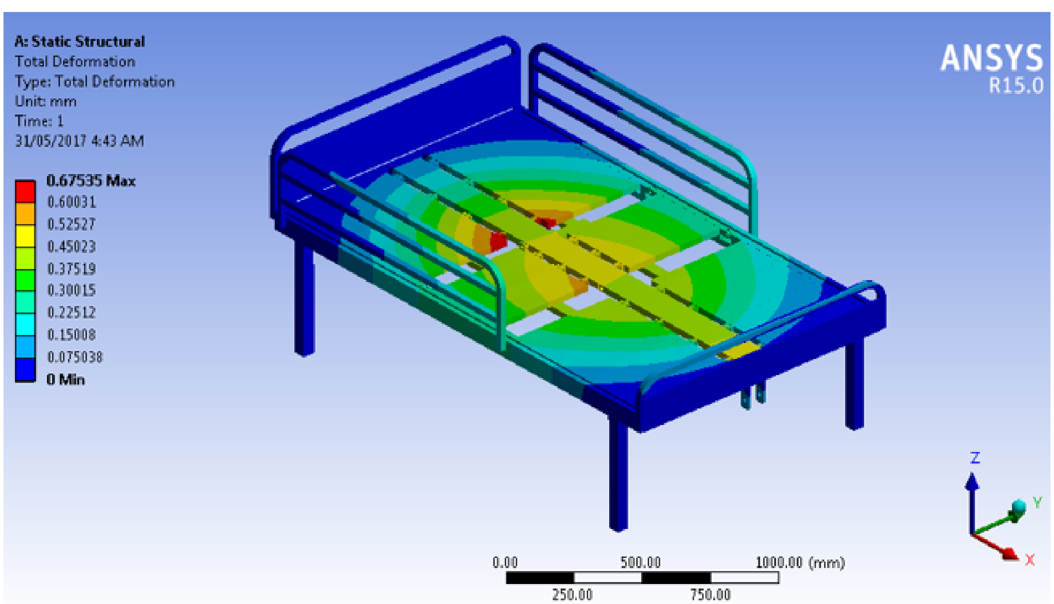


Figure 12: *Displacement distributions in bed frame, safe working load.*

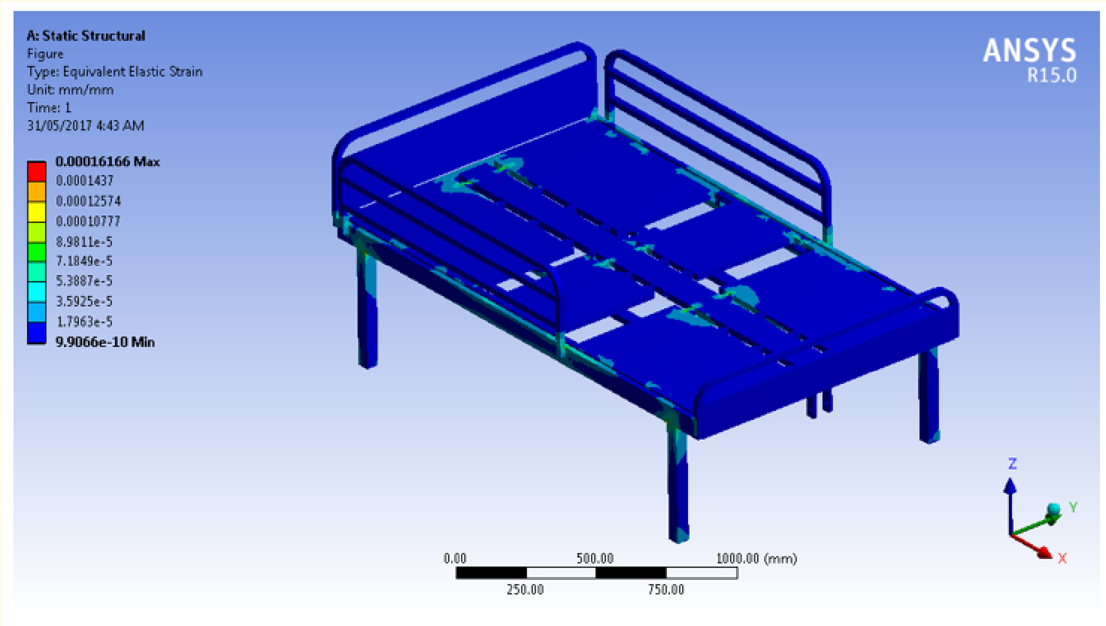


Figure 13: *Strain distributions in bed frame, safe working load.*

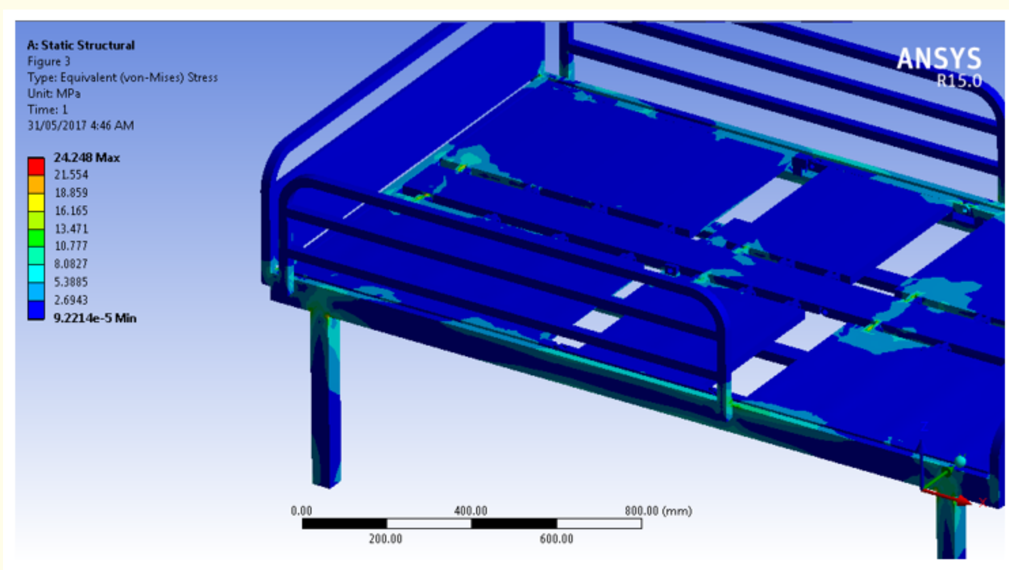


Figure 14: *Stress distributions in bed frame, safe working load.*

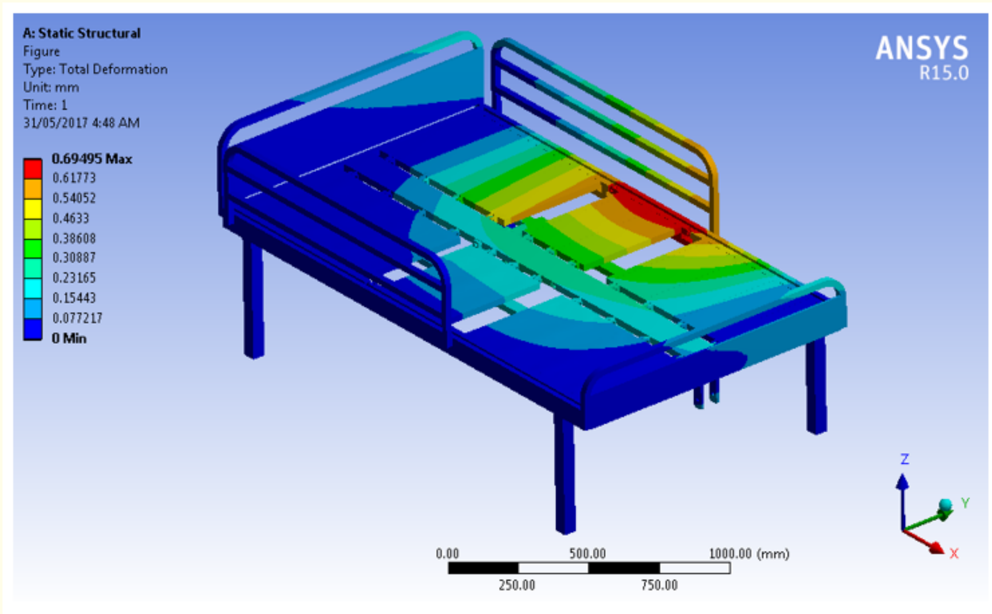


Figure 15: *Displacement distributions in bed frame, transverse stability.*

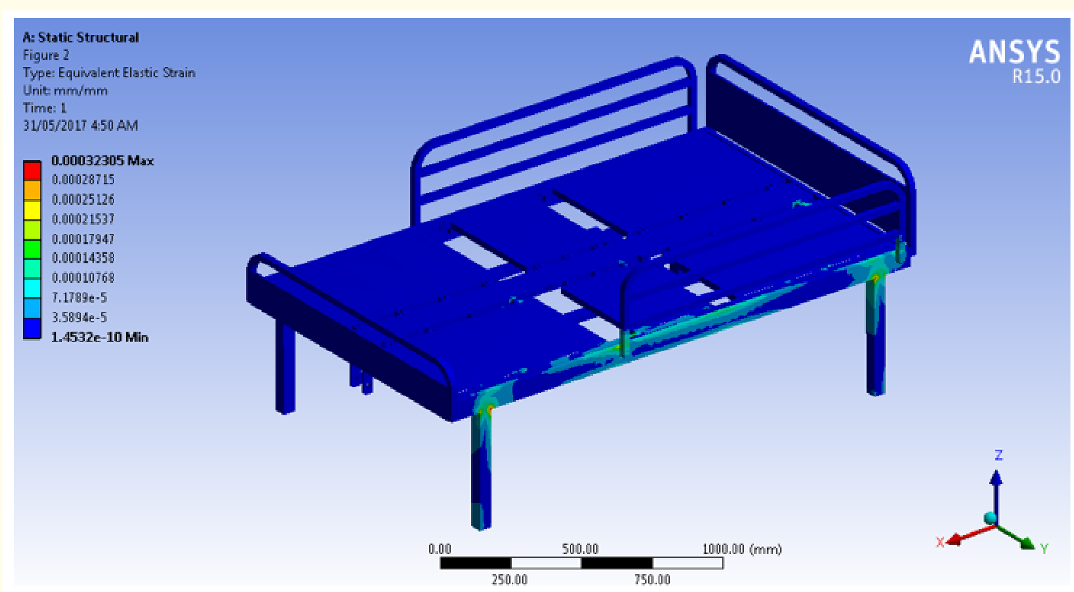


Figure 16: *Strain distributions in bed frame, transverse stability.*

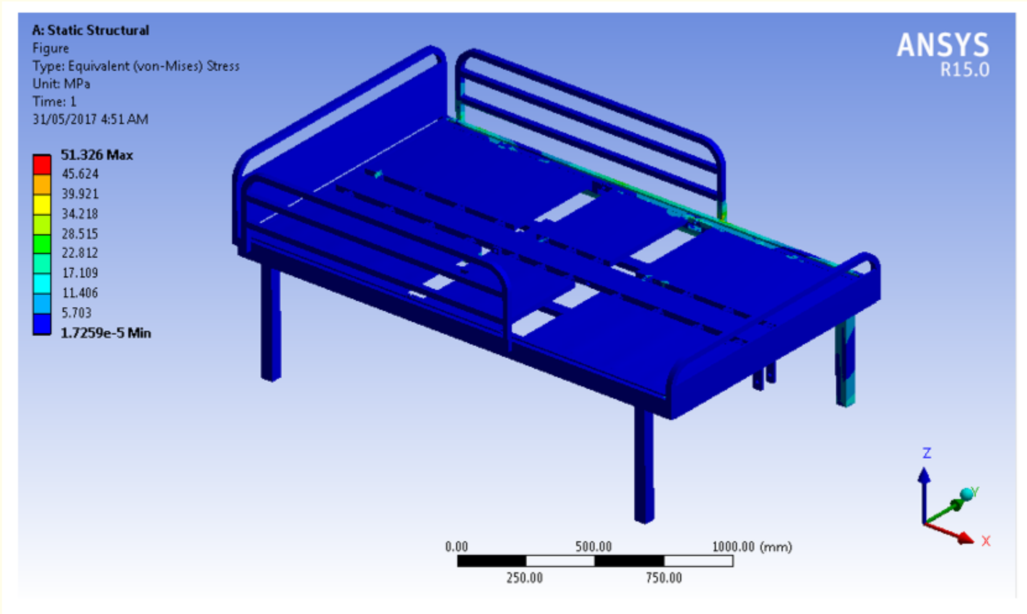


Figure 17: *Stress distributions in bed frame, transverse stability.*

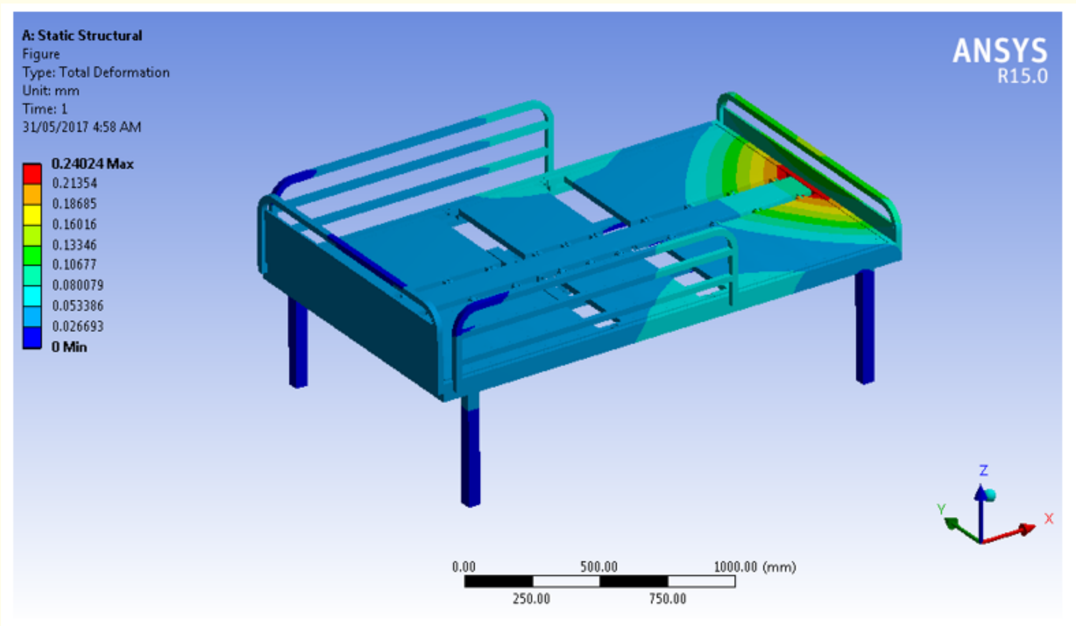


Figure 18: *Displacement distributions in bed frame, longitudinal stability.*

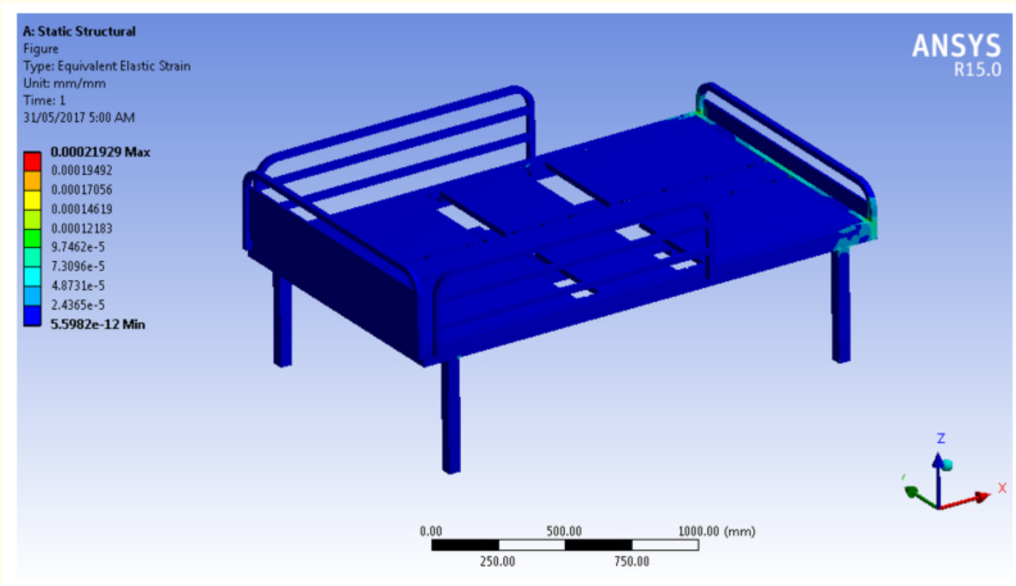


Figure 19: *Strain distributions in bed frame, longitudinal stability.*

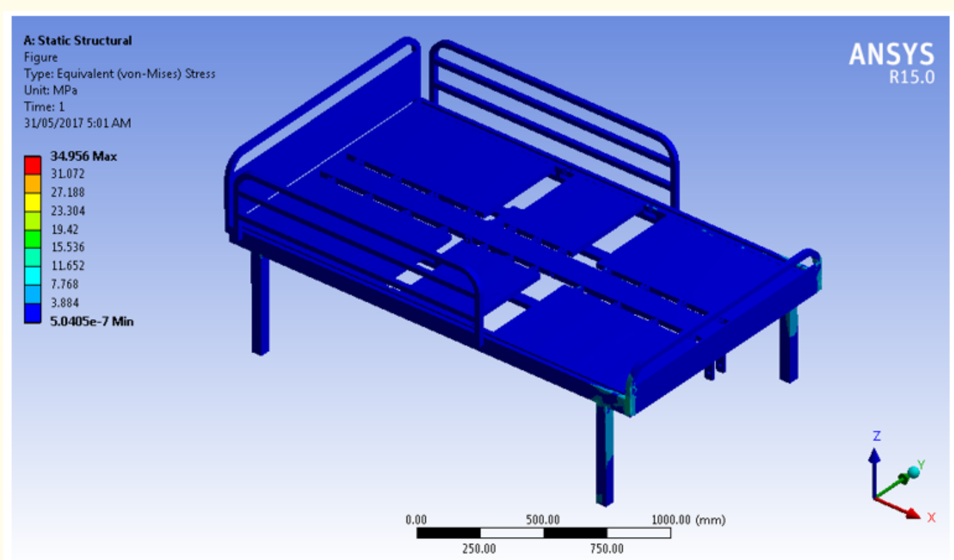


Figure 20: *Stress distributions in bed frame, longitudinal stability.*

Table 2 Summaries displacement, mechanical strain and von misses stress developed in bed model for given loading conditions.

Sr. No.	Variants of loading	Loading value	Displacement (mm)	Total Mechanical Strain (Ɛ, %)	Von Misses Stress ɛ, MPa
1	Safe working load	1700N	0.67	0.00016	24.24
2	Transverse stability	1500N	0.69	0.00032	52.32
3	Longitudinal stability	2250N	0.24	0.00021	34.95

Table 2*: Results of the FEM analysis of the bed structure.*

Conclusion and Future Scope

A new, low cost mechanically operated lateral tilting bed is designed and presented in this paper. Main feature of the bed is that it can tilt laterally to reposition the patient side to side as and when required. The bed converts into a chair when using for patient feeding purpose. This facilitates easy day to day handling of bedridden patients and makes the patient more comfortable. New mechanisms were designed for lateral tilting of bed. The bed was utilized by patients for use and the feedback was satisfactory. Few doctors and nursing staff also appreciated the new design. Thus, additional facilities provided on newly designed model helps caretaker to reposition patient with minimum efforts and ultimately helps to prevent PUs.

Some more mechanisms to operate specified locations on bed by dividing bed in few segments (profiles) may be explored and developed. Operating at respective segments, it is possible to relive pressure at that segment.

Current bed is fabricated with structural steel which increases weight as well as cost of the bed. With different composite materials one can manufacture the bed with low weight and cost.

There is a need to add few more functions like height adjustment trendelenburg movements of the bed which are not incorporated in the existing bed due to complex design.

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