Research Article

Design and development of multifunctional patient bed with integrated toilet

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Received: 1 June 2021 / Accepted: 8 September 2021
Published online: 27 September 2021
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Abstract
This paper presents a new bed for bedridden patients. It has provision for using a commode by pulling it up to the bed height by a specially designed mechanism. For commode use, it has an opening in the bed. A mattress on the platform covers the commode opening. After use, the commode is pushed back to its position below the bed. Then, the commode opening gets covered. This bed also has provision for side turning of the patient. The left and right-side turning mechanisms can operate independently to allow the patient to sleep on the left or right side. It is possible to turn both sides together to avoid touching the middle part of the back to the bed surface to avoid pressure ulcers. The side turning may be simultaneously operated with the backrest. A separate mechanism is there for this purpose. In addition, the bed can be converted into a chair position and has other utilities like a washbasin, folding table, and cistern attached to it. The bed design and development are in two stages. First, a bed with a commode is designed. Later, this design is improved to add a side turning mechanism. Computer modeling, simulation, fabrication, and testing are employed to plan and check bed operations and positions. The mechanical performance of the bed is compared with the simulation results, and the errors are negligible. The bed is compared with the reported designs in the literature. It is a novel product. It will be excellent equipment for bedridden patients and caregivers.

Article Highlights

- Presents a new bed design for bedridden patients..
- The bed has the provision of a commode and a facility for the side-turning of the patient.
- Reduces discomfort for the patients, chances of bedsores, and efforts of the caretaker.

Keywords Patient bed design · Bed with commode · Side turning · Bedsores

1 Introduction

A recent report of the United Nations [1] shows that the world population is ageing, and the growth of the ageing population is the fastest in Asia, Latin America, and the Caribbean. The number of people over 65 is likely to increase from 702.9 million in 2019 to 1548.9 million in 2050. Many of these ageing people would be bedridden due to age-related mobility issues. In addition to age-related problems, many people are bedridden due to various diseases, accidents, surgeries, and other health issues. The bedridden patients need full-time care and attention. Family, friends, nurses, and other professionals provide this care and attention [2]. Such patients need assistance

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for various frequently performed (more than ten times in a day) tasks such as invasive procedures, maintaining hygiene and patient comfort, mobilization in bed, and feeding [3]. The frequent assistance needed in all these tasks also results in embarrassment, discomfort, and loss of dignity for the patients [4]. The caring tasks generally involve the lifting of patients [5, 6], or other movements [7, 8]. As reported in the literature, manual handling of patients is one of the major causes of musculoskeletal disorders in the nursing staff and caretakers. Serranheira et al. [3] studied the tasks of hospital nurses and work-related musculoskeletal disorders among Portuguese nurses. Bed feeding to the patient, hygiene, and care had a dominant effect on low back pain. A study on 3341 health workers in various hospitals and geriatric residences of Northern and Central Italy performed by Colombini et al. [5] revealed that health care professionals working in homes for the elderly, rehabilitation centers, orthopaedic and surgical departments where manual handling of patients is the main activity, are more at risk to have the spinal disease. Retsas and Pinikahana [6] carried out a study on 523 nurses working in Australia to find the correlation between the manual handling of patients and injuries to nurses. 40.1% of nurses had injuries related to manual handling activities. Abedini et al. [7] collected the data of 400 nurses in 11 hospitals and found that 83.5% of nurses were at risk of developing musculoskeletal disorders due to manual patient handling. A similar study on 394 nurses involved in patient care activities by Passali et al. [9] in Greek hospitals showed a 98% prevalence of musculoskeletal disorders among nurses. Kee and Seo [10] reported musculoskeletal disorders among nursing personnel in Korea. The shoulder was the most susceptible part for musculoskeletal disorders. The other parts at risk were—knee, lower back, hand/wrist, neck, ankle/feet, finger, and others. Zhou and Wiggermann [11] have studied the effects of hospital bed features on physical stresses on caregivers at the time of repositioning the patients in the bed. They reported a greater risk of shoulder and upper extremities injury to caregivers during lateral repositioning and turning. To reduce the injury risk, they suggested using mechanical lift equipment. However, in another study, Wiggermann et al. [12] concluded that repositioning aids are not sufficient to eliminate the risk of musculoskeletal disorders because of patient handling tasks. Visntrup et al. [13] have also recommended using lifts and intelligent beds to avoid musculoskeletal injuries to the caregivers. Apart from the chances of musculoskeletal disorders for the caretakers, one major problem encountered in caring for bedridden patients is the bedsores or pressure ulcers [14]. A key recommendation for preventing bedsores is to roll over the patient every two hours to alleviate contact pressure on the body parts [14, 15].

From the above discussion, it is clear that there is a definite need to provide special equipment or beds for bedridden patient care to minimize assistance required for the patients to make the patient comfortable, prevent bedsores, and reduce the risk of musculoskeletal disorders for the caretakers. Presently, the available beds have either only a commode with a seating position or only a side turning arrangement. Previous researchers did not combine the commode, seating, and side turning mechanisms in one bed due to restrictions of motions and available space. Hence, the research gap is to design a bed with a combination of mechanisms enabling independent and simultaneous operation of the side turning to prevent bedsores, commode to avoid bedpan and associated discomfort, and seating position to use a commode and other necessities. Such arrangement will also reduce the risk of musculoskeletal disorders to the caregivers as patient handling is reduced. In this context, this paper presents a new bed designed by the authors. Hereafter, the manuscript organization is as follows.

The second section reviews the bed designs reported in the literature. The methodology used for designing the bed is presented in the third section, followed by the details of the newly designed bed in the fourth section. Later, the fifth section presents the results of testing the new bed and its comparison with the simulation results. The sixth section compares the novel bed design with the reported bed designs and highlights the uniqueness of the present bed. The conclusion is the last section.

2 Review of reported bed designs

One can find different designs of beds reported in the literature. Mascaro et al. [16] designed a hybrid wheelchair/bed system named RHOMBUS (Reconfigurable Holonomic Omnidirectional Mobile Bed with Unified Seating). Binayak Roy et al. [17], 18 used a flexible sheet for repositioning a patient in a rehabilitation bed. The purpose was to reduce the risk of bedsores. Basmajian et al. [19] also proposed a similar bed called a marionette bed. Ching-Hua et al. [20] designed a bed with lateral positioning and transfer of patients. It also allowed patients to change position from lying to sitting or feet rising gesture. The lateral turning was by using an inclined bedsheet by lifting it from one end. However, in this arrangement, the patient could not remain in the sideways position for a long duration as there is a tendency of sliding on the inclined bed sheet. Tan et al. [21] proposed a robotic nursing bed for paralyzed patients. It had provisions of raising back, curling legs, side turning, and voice recognition control. Peng and Lian [22] designed a multifunctional bed for bedridden patients. It had a device for transferring patients from the

bed to a wheelchair and vice versa. Peng et al. [23] later proposed a multifunctional system having two robotic beds. It had the main bed for posture changing and a nursing bed for transportation. The design also included a belt system for transferring the patient from one bed to the other. Pandiyan et al. [24] proposed a robotic assistance system for the bedridden. The system helped to lift the patient from the sitting position. Abdulrazaqet et al. [25] also designed a multifunctional, portable bed having an adjustable backrest, thigh rest, and shank rest. Recently, Kajol et al. [26] proposed a voice actuated bed for patient care. Soonthornkiti and Jearanaisilawong [15] designed an anti-bedsore bed. They used a mechanism to change points of contact between the body of the patient and the bed to prevent bedsores. Aruna Singh et al. [27] proposed a bed to prevent bedsores. Hong [28] also designed a Smart bed with pressure sensors for preventing bedsores. Goeran Fiedler et al. [29] also focused on the issue of bedsores. They developed a bed having an adaptable surface for prophylaxis and treatment of bedsores. The surface reduced the average contact pressure in prolonged bed rest and considerably reduced the onset and growth of bedsores.

Different approaches are also observed in the patents to get side turning by lifting bed sheets or cloth or belts placed below the body with the help of mechanisms placed below or above the bed. Smith [30] designed an attachment to be fixed on the bed with a set of belts placed below the patient's body driven by two shafts on either side of the bed to lift the patient. Palmer [31] designed a mechanism with powered rotating drive rollers on each side of the bed. A continuous belt is there on each pair of rollers. The frames holding one inner and one outer roller each can rotate about the axis of the inner roller to turn the patient. Ching Hua Wei [32] designed a turning mechanism using cloth fixed on two frames whose positions could change to turn the patient.

As discussed in the previous paragraphs following points are observed from the literature.

- The design approaches mainly focus on automated or robotic systems using modern sensors with electronic or computer controls.
- The cost of automated beds with all the modern instrumentation and controls would be high.
- The beds having an arrangement for side turning are designed only for side turning. A combination of systems of side turning which can work with backrest and at the same time suitable for bed with commode does not exist.
- Only two references [33] and [34] presented beds designed with integrated toilets. The arrangements reported are shown in Figs. 1 and 2.

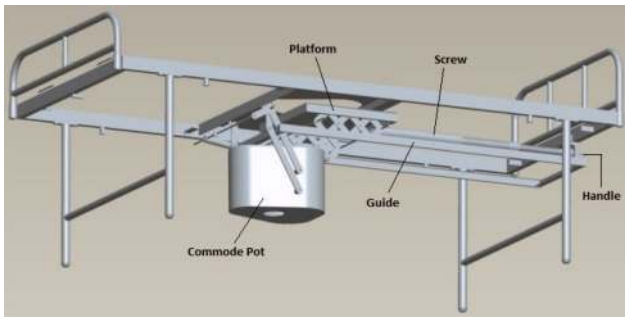

Fig. 1 Bed with commode [33]

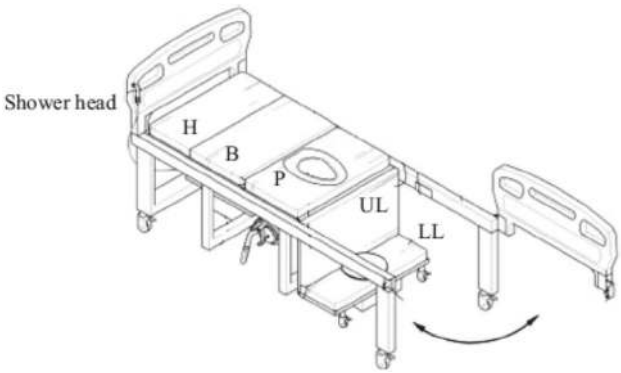

Fig. 2 Bed with integrated toilet [34]. H: head plate, B: back plate, P: pelvis plate, UL: upper leg plate, LL: lower leg plate

Based on the above observations, a low-cost bed with an integrated commode, having side turning, backrest, leg-rest, and the chair position is developed. Side turning is for alleviating bedsores, patient handling during sponging, and changing clothes and linen.

The following section presents the methodology followed and the new design developed by the authors. The present work shows the integration of a bed with a commode and the mechanism for side turning.

3 Methodology

To design the new bed following methodology was used. First of all literature review was carried out to identify the issues faced by bedridden patients, caretakers, and nursing staff while caring for them. The authors surveyed to know the expectations of the concerned. The survey was followed by a study of different bed designs reported in the literature. The purpose was to verify if the features available in available beds match with the expectations from the survey and requirements identified from the literature. Based on this study, the following needs are

identified: side turning, chair position, removable commode facility, and other utilities. The next step was to synthesize mechanisms to have side turning, chair position, and commode engagement and disengagement. Type synthesis, position synthesis, and dimensional synthesis of mechanisms were required. Different mechanisms were explored, and appropriate ones were selected. The sizes of the backrest, leg rest, hip rest, side turning parts, and commode arrangement were decided to fit on a standard hospital bed. Then, a computer model of the bed, including all the parts, was prepared. Selected mechanisms were then incorporated into the model. All the motions (length of travel, lift, turning angle), operations, and positions were confirmed. Later, the sizes of links, travels, strokes, and other relevant parameters were derived. Load on each component was calculated by considering the maximum weight of the patient as 120 kg. It was followed by component design for strength using standard mechanical design procedure. The computer model was updated, and once again, operation and positions were confirmed by simulation. Items like wash basin, folding table, utility rack, cistern, railing were also added to the updated computer model. Lastly, the designed bed was fabricated and tested for its operations, desired positions, and loads. The entire design was completed in two stages. In the first stage, only the commode arrangement was included, and then additional mechanisms for side turning were also incorporated in it after necessary modifications.

4 Design of bed with commode, side turning and seating

Drawings and solid models of all the components, the subassemblies (backrest with two parts, hip-rest with two parts, and side tilt mechanism), and the complete bed assembly were developed in the CREO modeling software.

Fig. 3 New bed with side tilting arrangement

Figures 3, 4, 5, 6, 7, 8 and 9 show the images of the new bed with side turning and commode. The majority of the bed components except the side turning part remained the same as in Fig. 1 [33]. However, the component sizes were modified for fitting the side turning arrangement. The assembly was checked for the correctness of dimensions. Interference or gaps between components, if any, were eliminated.

A mechanism for side turning (to the left or right) of backrest and hip-rest was developed. Further, a telescopic mechanism was developed for backrest operation. The mechanism operates the backrest even when the side is upward or allows side turning when the backrest is vertical. A patent is filed for this arrangement. Figures 3, 4, 5, 6, 7, 8, 9 show various features and positions of the bed with side turning. As seen from these figures, the bed has a sleeping position (Fig. 3), same as in the previously designed bed, but having backrest and hip-rest divided into two parts, and commode pot is shown in the upward position. Figure 4 shows a drawing of the side turning mechanism in the sleeping position. Figure 5 shows drawings of the side turning mechanism in the backrest up position. Figure 6 shows the backrest up position. Figure 7 shows the highest side up, and backrest position which can be achieved without the interference of any part with the other. Figure 8 shows a drawing of the side turning mechanism in the side

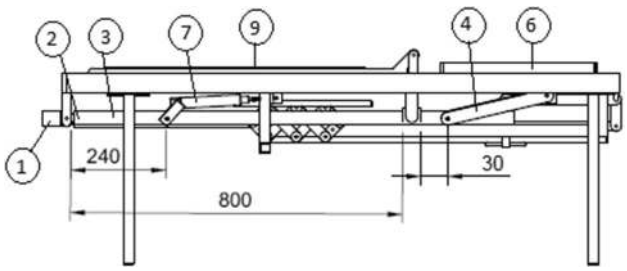

Fig. 4 New bed—sleeping position. (1: Screw, 2: Nut, 3: Sliding member, 4: Link, 6: Hip-rest, 7: Link, 9: Backrest)

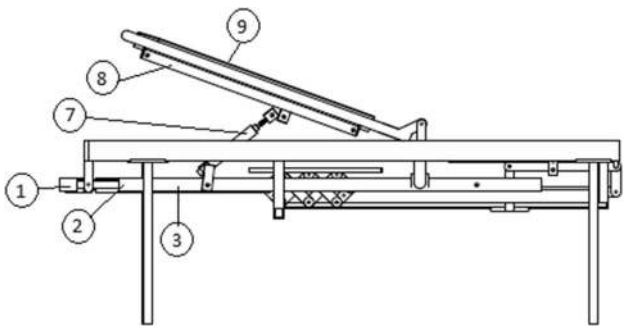

Fig. 5 Bed—raised backrest position. (1: Screw, 2: Nut, 3: Sliding member, 7: Link, 8: Shaft, 9: Backrest)

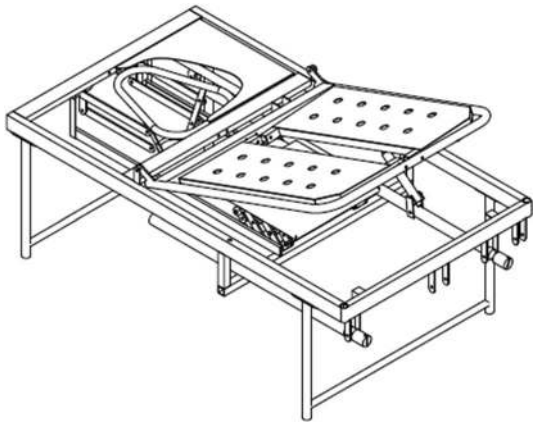

Fig. 6 Another view of raised backrest position

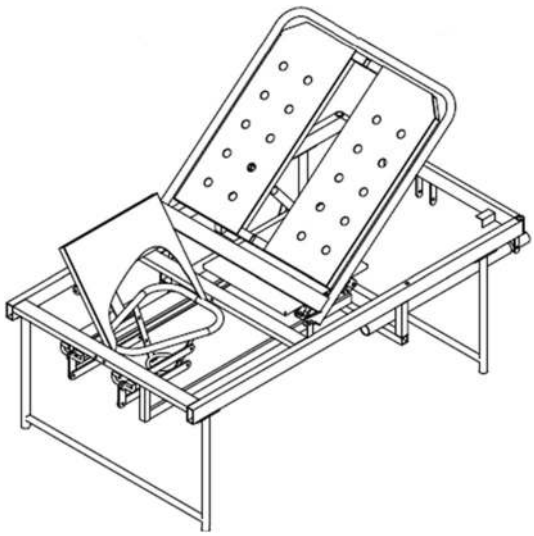

Fig. 7 Raised side and raised backrest position

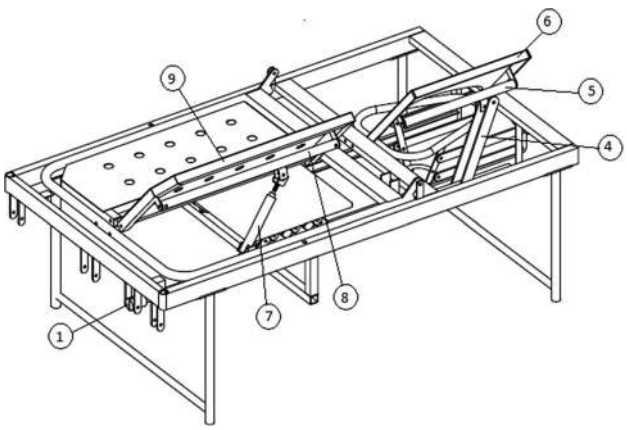

Fig. 8 Side in the raised position. (1: Screw, 4: Link, 5: Shaft, 6: Hip-rest, 7: Link, 8: Telescopic link, 9: Backrest)

Fig. 9 Photo of bed in raised side position

up position. Figure 9 shows an actual photograph of the side turning mechanism in the side up position.

Referring to Figs. 4, 5 and 8, the side turning mechanism is actuated by a telescopic screw (1) and nut (2). It pushes a sliding member (3) towards the leg side. This sliding member is connected to the hip-rest part by a link (4) which is connected to a rotating shaft (5) below the hip-rest (6). When the hip-rest is lifted, the rotating shaft (5) adjusts itself for the angle of the hip-rest and avoids twisting of the link (4). This same screw and nut mechanism pushes a sliding member (3) towards the leg side, is connected to the backrest part by a link (7) connected to a rotating shaft (8) below the backrest (9). When the backrest is lifted, the rotating shaft (8) adjusts itself for the backrest angle and avoids twisting the link (7). Both backrest and hip-rest actuation are similar except that the link (7) below the backrest is telescopic. The telescopic link (8) expands to adjust length change due to simultaneous operation of backrest and side turn and prevents mechanisms jamming with each other.

5 Bed performance results

The bed and its mechanisms of Figs. 3, 4, 5, 6, 7, 8, 9 were modeled in CREO Design software. This modeling enabled the assembly of the parts and simulation of the desired motions. It also helped to verify the link motions. The model was tested for performance, and the results are shown in Table 1. It is observed that the link motions in the actual bed are similar to those in the computer model. The difference in the modeled and actual screw travel is because of the joint clearances.

Further investigations on different parameters like—time-saving, effort and assistance reduction, comfort to the patient, hygiene improvement, and other relevant issues can be taken up separately after fabricating more

Table 1 Mechanical performance of the proposed bed

Sr. No	Operation	Component	Designed parameters in CAD Model			Actual performance of fabricated bed			
			Screw travel (mm)	No. of rotations	Thread pitch (mm)	Screw travel (mm)	No. of rotations	Time (s)	Load (kg)
1	Individual	Backrest	150	30	5	145	29.5	15–20	120
2	Individual	Side Turn	150	30	5	140	28.0	15–20	120
3	Simultaneous	Backrest	150	30	5	145	29.5	30–40	120
4		Side Turn	150	30	5	140	28.0		

of such beds. The bed was demonstrated to a few Doctors and nursing staff who appreciated the bed design.

6 Discussion

There is no previous design of bed that has all the functionalities as the use of commode, side turning, conversion from sleeping position to chair position, and other functionalities. Therefore, the proposed design is unique. The new bed presented in this paper is compared with previously designed beds with similar features. It shows the following differences.

In the new bed, the commode operates by a specially designed screw mechanism. The commode is brought in usable position or retracted from it from the bottom side of the bed without disturbing the patient. Yeom et al. [34] had also proposed a bed with an integrated toilet. It uses a pelvis plate (Fig. 2) to connect the toilet basin to the bed. In this arrangement, the toilet basin always remains in the same position and cannot move down. Also, patient shifting is necessary for the opening or closing of the cover on the toilet basin. As reported by various researchers, handling patients is always risky and causes musculoskeletal disorders among the caregivers [3, 5, 6] [11]. Therefore, this bed with only an integrated toilet will always be risky for the caregivers.

The newly designed bed is split across width and length (Figs. 6, 7, 8, 9). The widthwise separation allows motions for the right or left turning of the patient in the bed. The lengthwise separation allows movement of the backrest, leg rest, and conversion from sleeping position to chair position while using the commode or other utilities. Such arrangement for avoiding the risk of bedsores and other patient care activities is also not found in the previous designs. Shinde and Rajhans [35] have proposed a bed with a lateral tilting arrangement to reduce pressure ulcers. The mechanism consisted of the lead screw and bevel gears. However, this bed did not have a chair position. It also did not have any toilet attached to it. Soonthornkiti and Jearanaisilawong [15] have used a complex system of changing contact points between the body and the bed support to alleviate bedsores. Roy et al. [17, 18] have used a flexible sheet to turn the patient in bed. Basmajian et al. [19] and Ching-Hua et al. [20] have also used the same concept for lateral turning of patients in bed. The bed designed by Lin Tan et al. [21] has lateral turning by using different boards (plates). The method of moving the boards is also different. Hong [28] used many sensors below the mattress to monitor and control contact pressure for reducing the risk of bedsores. Fiedler [29] et al. used an adaptable bedding surface to prevent pressure ulcers. Thus, there is no attempt to integrate the concept of having commode and side turning of the patient in bed. This integration is achieved in this paper.

The mechanical performance of the new bed was compared with the simulation results, and it was satisfactory. Further, the bed was tested by applying load on the platform to check operations under load and find the amount of friction in operating the bed. The load test results were also satisfactory. Two recently granted patents for the concept and mechanism design confirm the novelty of the bed and its features.

7 Conclusion

This paper has presented a new bed integrating side tilting of the patient, attachment of commode, and seating position of the patient. New mechanisms were designed for side turning (rollover) of the patient in bed. The main highlight of the bed is that it allows simultaneous operation of the backrest and side turning. Further, it also has a commode to use as and when required. The bed can also convert into a chair while using the commode. It also facilitates changing of clothes & bedsheets and helps to prevent bedsores. The use of this bed will result in less effort for managing bedridden patients. As the patients do not need to use a bedpan, all the problems associated with a bedpan are avoided. Patients will become more comfortable. Bedsores and risk of musculoskeletal disorders to caregivers will reduce.

The bed offers significant improvement in the management of bedridden patients. Two recent patents have

confirmed the novelty of the bed and its features. This bed is mechanically operated and therefore will cost less. It is affordable for economically weaker sections of the population. The bed can also be motor-driven by providing few controls to make it a remotely operated bed. As the load test and preliminary usage feedback are encouraging bed can be put to actual use. However, more trials are required to gauge the impact of the bed on patients and caregivers.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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