Design and Development of Portable Support Surface and Multilayered Fabric Cover for Bed Sore Prevention

P. Kandha Vadivu

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Abstract Pressure ulcers are serious and common health concern affecting about 1.5–3 million adults and is a serious health concern for elders. Pressure ulcers or bed sores seem to be one of the most challenging inflicts to the doctors and may result in significant morbidity and mortality and are associated with high cost in terms of human sufferings, cost of treatment, and possible litigation. Though modern medical science has launched a variety of treatment methods, prevention is the best way to get rid of it. Pressure sores are best prevented by using support surfaces that are volatile in nature-like water mattress, variable pressure mattress, etc. In this research work, a portable support surface has been designed and developed for preventing bed sore. It consists of four individual components for the body part such as bodice back, hip, elbow, and heel which are likely to be affected by bedsores. Each component has volatile surface provisions in them with refilling and cleaning facility. The portable support surface is easy to wear and remove and also cheaper. Above all, the kit is user-friendly with no side effects and preferred and guaranteed by the doctors.

Keywords Pressure ulcers · Support surfaces · Portable support surface · Medical sheepskin · Multilayered fabrics

Introduction

Pressure ulcers (also known as bedsores, pressure sores, decubitus ulcers) are areas of localized damage to the skin

and underlying tissue due to pressure, shear, or friction. They are common in people who cannot move because they are paralyzed, recuperating from surgery for a prolonged time, being treated in intensive care for a long time, or incapacitated by severe arthritis, stroke, or spinal cord injuries or other neurological problems that decrease their ability to feel pain or discomfort.

Bedsores can develop in a matter of hours. Pressure as small as 60 mmHg to a body surface for 1–2 h initiates the process of skin breakdown. National survey in various countries reported a prevalence of bed sores around 14.8 % across the hospitals. A pressure ulcer of stage 2 or higher has been calculated to increase patients cost by a factor of 2.7, while the annual cost of pressure ulcer to the American health care system is estimated at 3.6 billion dollars. An attempt has been made through this work by designing and developing a portable support surface with individual components for different portions of the body which are easy to wear, remove, and carry. Above all, the kit is user-friendly with no side effects and preferred and guaranteed by the doctors.

Causes of Bed Sores

The abnormal loading of skin and other surface tissues unaccustomed to bearing large mechanical forces occurs under many circumstances of chronic disease or disability. A result of abnormal loading is breakdown of the body wall tissues. There is also compelling evidence that factors in addition to pressure are contributors and must also be considered when attempting to fully understand the pressure-sore phenomenon. Studies have analyzed the roll of implicated factors such as shear stress [1], impact loading of tissue [2], elevated temperature and humidity [3, 4], age, nutritional

P. Kandha Vadivu (✉)
Department of Fashion Technology, PSG College of Technology,
Coimbatore 641004, India
e-mail: vadivu67@yahoo.co.in

status, general health, activity level [5], deformity, posture and postural change [6, 7], body stature [8], and psychological deficits through various research works.

Increased friction and shear, poor nutrition, disease, and pressure all aggravate compromised skin. Even the chemical irritation of frequent washings with soaps can cause irritation. The adhesiveness of moist skin to bed linens is estimated to increase the risk of ulceration fivefold. The roll of few causative factors in pressure ulcer development is listed below.

Pressure

Bedsore form where the weight of the person's body presses the skin against the firm surface of the bed. The pressure that causes bedsore does not have to be very intense. Pressure of less than 25 % the pressure of a normal mattress can lead to bedsore. Complete muscle necrosis was demonstrated at 100-mmHg (13 kPa) for 6 h and pressures of 70 mm Hg (9 kPa) for 2 h resulted in pathologic changes within muscle and lower pressures of 35 mmHg (5 kPa) for 4 h resulted in no changes [9].

Shearing and Friction

Shearing and friction causes skin to stretch and blood vessels to kink, which can impair blood circulation in the skin. In a person confined to bed, shearing and friction can occur when the person is dragged or slid across the bed sheets. Shear stress occurs when a force is applied in the plane of the skin surface. Friction occurs when there is displacement between the skin and the supporting surface.

Moisture

Wetness from perspiration, urine, or feces can make the skin too soft and more likely to be injured by pressure. Moisture from sweating or incontinence will hydrate the skin, dissolve the molecular collagen cross links of the dermis, and soften the stratum corneum. Another result of skin hydration is the rapid increase of the epidermal friction coefficient, which promotes adhesion of the skin to the support surface and increase shear, easy sloughing, and ulceration.

Temperature

Elevated body temperature raises the metabolic activity of tissues by 10 % for every 1 °C of temperature increase, concurrently increasing the need for oxygen and an energy source at the cellulose level. If the patient has impaired circulation from local pressure and shear, tissues will starve and release lysozymes, inducing autodigestion of the cytoplasm and reducing skin integrity. It has been shown in animal studies that pressure-induced tissue injury accelerates with increasing body temperature [10].

Other causes include poor nutrition, age, very thin (emaciated), over weight (obese), and suppressed immune system, radiation therapy, chronic diseases, incontinent, trauma, swelling, and infection. Pressure ulcers occur most frequently over areas where bones come close to the surface. The most common sites are the elbows, heels, shoulders, shoulder blades, sacrum, hips, ankles, ears, knees (inner and outer parts), and buttocks.

Pressure Relieving Support Surfaces

Many types of pressure relieving support surfaces are available such as water beds, sheepskins and Australian Medical sheepskin made of high quality wool, etc. An attempt to reduce pressure on a bony prominence is based on two concepts. Either area in contact with the support surface can be increased or contact can be temporarily removed or shifted to other areas. In the first case, immersion and envelopment are the phenomena that produce reduction in pressure at bony prominence. In the second, the change in areas of contact over time is the therapeutic consideration. Different types of support surfaces such as Australian Medical Sheepskin, water beds, variable pressure mattress, air fluidized bed, lateral rotation bed, and low air loss bed, repositioning of patients are in use to prevent pressure ulcer formation.

Design and Development of Portable Support Surface

In an attempt to overcome the problems faced by the bedridden patients, and to fulfill the basic requirements of bedsore prevention, the following product development was initiated.

The main objective of this work is to develop a multipurpose, user-friendly, portable support surface for preventing bedsore which could overcome the defects of the water mattress such as

- Heaviness due to more volume of water present
- Difficulty in moving the water bed
- Non-suitability for other applications like wheelchair cushion, etc

Hospital Survey

A questionnaire was prepared and survey carried out in various hospitals to analyze about the causes of pressure sores, common areas of attack, type of support surface used, percentage of people affected, time taken for a patient to develop pressure ulcer, the type of preventive measures adopted in hospitals, approximate expenditure for treatment, the awareness or knowledge of the family members to nurse the pressure ulcer patients, etc.

It was observed that no special support surface was used in hospitals; instead, the hospital mattress used was very hard with rexin top cover which generates heat, aggravating the problem of pressure ulcer. The water bed was costly and unaffordable to most of the patients.

Design Description of the Kit

The basic principle used in the construction of this kit is “person resting on a volatile surface.” The volatile surface used in the support surface helps in reducing the pressure at the pressure points and hence bed sores are prevented at the initial stage itself. The portable support surface is designed to match the shape of the individual body parts. For example, the top garment is designed in the shape of a bodice block and the hip garment in the shape of a skirt block, in such a way that the patient experiences maximum comfort while wearing it. It is easy to wear and remove as it is constructed with Velcro tapes. The kit contains four individual components for different parts of the body namely

- Top garment
- Hip garment
- Elbow pad
- Heel pad

The design description of each component is described below.

Top Garment

The top garment is in the shape of a bodice block and covers from shoulder to hip. It consists of three parts such as:

- Water bag in the shape of bodice
- A fabric cover over the water bag which is made of multilayered fabrics
- Front panel cloths to cover the front of the body

The top garment water bag is made of a breathable PVC material in the shape of bodice. A flexible water nozzle is placed at the back covered with the cap. This can be pulled out to pour water in/out. After the water bag is filled with water, the nozzle is pushed in. The capacity of the top garment is 8–10 l. The water bed conditioner is poured along with it to avoid foul odor from water bag. The top garment covering cloth is made of multilayered fabrics in the shape of a bodice pattern with provision for fastening at the side (Fig. 1).

The multilayered fabric cover is placed above the water bag so that it acts as a barrier between the patient's skin and the PVC material. Thus, the skin is in contact with the multilayered fabric only and not with the PVC material. The multilayered fabric cover is made of one layer of Lyocell twill and two layers of Lyocell terry fabrics which is a better combination for bed sore prevention in all aspects like air

Fig. 1 Components of top garment

permeability, thermal conductivity, and moisture management properties. The slots in this cover helps in inserting and placing it above the water bag. In case of any stains, the fabric covers can be removed and washed.

The front panel is made of cotton, bamboo, or lyocell fabrics for comfort and cool feel. This is joined to the back panel with the velcro straps provided. The cross-sectional view of the water bag and the multilayered cloth cover is shown in Fig. 2

Hip Garment

The hip garment is in the shape of a skirt and covers from the hip till the calf. It also consists of a water bag, multilayered fabric covers, and back panel in the shape of a skirt pattern.

Hip garment is also arranged similar to top garment with the water bag at the bottom over which a multilayered fabric cover is placed for improving the comfort properties. The front panel is fastened to the back by velcro fastening (Fig. 3).

Elbow Pad and Heel Pad

The elbow pad covers quite a larger area in the middle of the arm. It consists of two parts:

- Rectangular air bag
- Multilayered fabric covers

Fig. 2 Support surface and multilayered fabric cover

HIP GARMENT-BACK

Fig. 3 Components of hip garment

The rectangular bag is made of a breathable PVC material, with Velcro straps at the sides to fasten. Unlike the top and hip garments, it consists of air valve. The air valve is opened and air is blown inside, as per requirements. The multilayered fabric cover is placed over the blown air bag. Now, patients elbow could be placed on it and the Velcro straps could be fastened. The heel pad is similar to elbow pad.

Directions for Use

The kit is designed with simplified design features and involves very simple procedure of usage which enables even the common people to use the kit with ease. The directions for use are given below.

Fill the water bag (top and hip garments) with water and pour a small amount of conditioner in it. Close the nozzle and push it inside.

Place the water bag (top garments and hip garments) on bed so that the nozzle is at the back (facing the bed). Now, insert the washed fabric cover (top garment and hip garment) in the slots provided.

Make the patient to lie down over these arrangements.

Now, the front panel (for top and hip garments) is joined with the Velcro straps provided.

Fill the elbow pads and heel pads with air and close the nozzle.

Ensure that the nozzle is facing down while placing it on the bed.

Washed fabric covers are placed above the air bags

Now, the Velcro straps are used to fasten the air bags to the patient's elbows and heels

The water-filled- and air-filled components act as an efficient support surface for the parts in contact with the hard mattress and relieve point pressure by increasing the area of contact and immersion.

Instructions for Kit Care

The support surface is provided with a kit care unit which contains water bed conditioner, emery paper, PVC patches, and an adhesive. The care and maintenance procedure for the kit is listed below.

Use about 40 ml of water bed conditioner in top and hip component along with water

In case of any holes or puncture in the PVC material, rub the surface with the emery paper given and stick the PVC patch using the given adhesive solution

The kit has to be frequently checked for holes, if any Water should not be filled in excess of its capacity

Fig. 4 Patient wearing support surface kit

Wash the multilayered fabric cover whenever necessary, for hygienic protection

Advantages of Portable Support Surface

The support surface can be used as a complete set for the hospitalized patients (Fig. 4) or partially for the patients in a wheelchair as per the patient's need. This kit has the following unique advantages

The fabric covers can be easily removed and washed, if stained.

The component fits to any size of the patient.

Because of Velcro fastening, the kits ensure absolute ease of wear and unwear to the patients.

Since it is lighter than water mattress, it can be easily moved or carried to any place.

It can also be used on a wheelchair, whenever patient requires.

The kit is compact and portable.

If not in use, water can be drained and the components can be packed and stored in its bag.

Doctors' Feedback

From the feedback of the doctors it is clear that

The kit is user-friendly and causes no side effects

The patient wearing the garments feels comfortable

It is hygienic and easy to use

It is multifunctional, i.e., it can also be used for patients confined to wheelchair

It is cost effective

Testing Procedure

The performance of support surface with multilayered cover sheet was analyzed for the interface pressure, temperature, and comfort characteristics by subjective and objective analysis. The distribution of pressure and shear forces are determined by a number of physical properties including stiffness and elasticity of the cover material.

Measurement of Interface Pressure Between the Body and Support Surface

A new pressure measurement system with self-inflatable balloon, Kikuhime (TT Medi Trade, Soledet 15, DK 4180 Soro), was used to measure the interface pressure between the body and the support surface. The instrument was composed of two self-inflatable air-filled balloons, a connecting tube, and a measuring unit. The small, flexible, air-filled pressure bladder has a dimension of 30×38 mm and is about

Table 1 Interface pressure between the body and support surface in a wheelchair

Sample no.	Part of the body	Pressure developed				Body weight 45 kg				Body weight 52 kg				Body weight 71 kg				Body weight 91 kg			
		Commercial chair cushion	Developed support surface	% reduction in pressure	% reduction in pressure	Commercial chair cushion	Developed support surface	% reduction in pressure	% reduction in pressure	Commercial chair cushion	Developed support surface	% reduction in pressure	% reduction in pressure	Commercial chair cushion	Developed support surface	% reduction in pressure	% reduction in pressure	Commercial chair cushion	Developed support surface	% reduction in pressure	% reduction in pressure
1	Back of the seat area	48	28	42	44	57	32	44	44	68	43	37	37	91	63	31	31	91	63	31	31
2	Center of the seat area	57	32	44	44	62	35	44	44	71	38	47	47	77	50	35	35	77	50	35	35
3	Front of the seat area	40	35	13	23	48	37	23	23	59	40	32	32	53	38	28	28	53	38	28	28
4	Thigh	32	28	13	27	38	30	27	27	54	33	20	20	41	22	46	46	41	22	46	46

3 mm thick when calibrated to zero and the other one is of 120×100 mm. The outer membrane of the balloons is made of polyurethane membrane of thickness about 200 µm for normal size and 100 µm for smaller size, and inside the balloon, also a polyurethane foam sheet is built in with a thickness of 3 mm. Normal size balloon is suitable for measuring a pressure at sacrum area, and so on. Smaller one is good at pressure measurement at limited area like a bone prominent area as heel. The instrument is capable of measuring pressure up to 200 mmHg.

Measurement of Body Temperature Using LM35

The LM35 series is a precision integrated circuit temperature true sensor whose output voltage is linearly proportional to the Celsius temperature. The LM35 thus has an advantage over linear temperature sensor calibrated in Kelvin as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling. The LM35 does not require any external calibration or trimming.

The LM35 low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supply.

Analysis of the Interface Pressure Between the Body and the Support Surface

In this study, pressure exerted on the body while sitting on the portable water bed and the hard hospital cushion was compared for patients with different weight range. The water-filled support surface ensures more area of contact in the high pressure areas of seat, where maximum body weight is transferred to the chair. The pressure measured on different portions of the seat portion of the body, on the wheelchair cushion, and the developed support surface are given in the Table 1.

The newly developed support surface ensures a pressure reduction of 13 to 44 % on different areas of the seat portion of the body. The portable support surface is designed to work on the principle of Pascal's law, which states that the weight of the body floating on the fluid system is evenly distributed over the entire surface as pressure is increasingly distributed over more body surface area and the intensity of pressure decreases over all body areas [11–13]. The support surface molds to the body shape, to maximize contact, and then redistribute the patient's weight as uniformly as possible.

Similarly when a patient lies for a long duration on the bed, unbearable heat is generated. This excessive heat creates restlessness to patients. The raise in temperature is measured on the patient's body while sitting on normal hospital bed and on the portable water bed

developed with multilayered fabric cover. The result shows that there is a considerable reduction in the raise in temperature when compared to normal hospital bed. The cool water bed along with the cool lyocell cloth cover reduces the rise in body temperature by 2 to 3 °C.

The disadvantages of a full size water bed as reported by common public is that a fluid-filled cushion is more difficult to transfer to and from the chair than a rigid or firm material because its center of gravity is constantly shifting, which requires rapid compensation on the part of the person attempting to lift and carry it. This is a difficult task for a patient with weak or poorly controlled musculature. The problem of seat cushion transfer is especially significant in clinical settings. One of the elements of portable support surface which give wheelchair users their greatest independence is the ability to transfer in and out of their wheelchairs, in and out of vehicles, etc. Since the portable water bed is divided into individual components and made weight less, it is easy to transport and made user-friendly. The cost of a full size water bed is around Rs 5000 and this portable support surface costs only Rs 800; hence, it very cheaper and affordable to all categories of patients.

Conclusion

From the survey conducted among 200 patients in various hospitals at Coimbatore, it was concluded that one of the causes for bed sore formation is the hard mattress used in the hospitals which increases the pressure on the body, generates excessive heat, and lacks in moisture management property. It was also realized that at least 50 % of the bedsores can be prevented by using simple measures like proper support surfaces. Considering the necessity for a user-friendly, portable, economical support surface, a kit was designed consisting of a top garment, hip garment, elbow pad, heel pad, and a water bed care kit. Field trial was carried out in two hospitals and the kit was approved and appreciated by the doctors. It has been proved that the kit can prevent bed sores to a great extent. If promoted in a large scale, this kit is sure to aid the suffering mass, extensively.

This development proves to be great relief to common people for whom even the medical expenses have grown to unreachable heights.

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