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Innovative Mattress Design: Evaluating Silicone Gel and Visco-Gel Pad Mattresses for Pressure Ulcer Prevention

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Abstract. Hospital-acquired pressure ulcers (HAPUs) are a prevalent medical issue, commonly known as bedsores, posing a significant risk to patients with limited mobility. Pressure ulcers develop due to prolonged pressure on soft tissues, leading to cell necrosis when muscle tissue is pinched between a bony prominence and a support surface. The development of advanced mattress materials, such as silicone gel, visco-elastic gel, and polyurethane foam, offers potential solutions to mitigate the risk of developing pressure ulcers. Current preventive measures focus on enhancing the skin-bed support interface and promoting postural and behavioral changes. This paper evaluates the effectiveness of, and proposes, an innovative mattress design utilizing silicone gel, visco-elastic gel, and polyurethane foam to prevent pressure ulcers. The study focuses on the structural design of the mattress and its impact on pressure ulcer prevention, comfort, and cost-effectiveness. Notably, a patent has already been granted for the mattress design discussed in this research.

Keywords: pressure ulcers, silicone gel, visco-elastic gel, polyurethane foam, mattress design, patient safety, standard hospital mattress.

1 Introduction

Pressure ulcers, also known as bedsores, pose a significant risk to patients with limited mobility, such as those in hospitals and nursing homes. These ulcers are caused by prolonged pressure on the skin, which can lead to cell necrosis due to restricted blood flow [1, 2]. Tom Defloor et al. [3] found that Standard Hospital Mattresses (SHM) offer minimal pressure-reducing benefits. The gel layer on these mattresses provided limited pressure relief. They determined that visco-elastic polyether and polyurethane were more effective in reducing pressure. However, they concluded that none of the mattresses studied were successful in completely preventing pressure ulcers. In the United States, prevalence rates in hospital settings range from 4.7% to 32.1%, while in nursing homes, they range from 8.5% to 22%. In Canada, a reported prevalence rate of 25.1% is associated with pressure ulcers, posing an elevated risk of mortality among the elderly [4,5]. The National Pressure Ulcer Advisory Panel (NPUAP) reported that the prevalence of pressure ulcers in general acute care settings ranges from 10% to 18% [6]. Effective preventive measures aim to reduce the intensity and duration of pressure and shear forces, thereby ensuring an adequate oxygen supply to tissues [7]. This study focuses on innovative mattress designs utilizing silicone gel, viscoelastic gel, and polyurethane foam to prevent pressure ulcers. The goal is to evaluate these materials from multiple perspectives, including their effectiveness in reducing pressure ulcer incidence, contact interface pressure, blood perfusion, comfort, and cost-effectiveness. [8]

2 Literature Review

This literature review examines various types of mattresses and their comparative effectiveness in reducing the incidence of pressure ulcers.

2.1 Comparative Analysis Over Various Foam and Air Mattresses:

Traditional foam mattresses have been a staple in hospital settings due to their affordability and basic pressure distribution capabilities. Studies, however, have shown that these mattresses often fall short in effectively redistributing pressure, particularly for patients with limited mobility. The static nature of foam can lead to increased pressure on specific body parts, which can exacerbate the risk of pressure ulcers. Research by Defloor et al. [9] demonstrated that while foam mattresses are better than standard hospital mattresses, they are not as effective as more advanced options.

Alternating pressure mattresses (APMs) function by periodically inflating and deflating air cells, redistributing pressure to minimize the risk of pressure ulcers. This dynamic mechanism simulates natural body movements and weight shifts, thereby reducing prolonged pressure on any single area. Research conducted by McInnes et al. [10] demonstrated that APMs significantly lowered the incidence of pressure ulcers compared to standard foam mattresses. However, these mattresses can produce noise, potentially disrupting patient sleep, which is an important consideration when evaluating their overall effectiveness.

Air-fluidized beds utilize a fluid-like medium generated by directing air through a finely particulate substance, such as silicone beads. These beds offer notable advantages for individuals with severe pressure ulcers or those at heightened risk. They excel in pressure redistribution and effectively mitigate shear and friction.. A systematic review by the National Pressure Ulcer Advisory Panel (NPUAP) highlighted the superiority of air-fluidized beds in healing stage III and IV pressure ulcers, though their high cost and maintenance requirements can be prohibitive [6].

Low-air-loss (LAL) mattresses provide a continuous flow of air to help keep the skin dry and are designed to conform to the patient's body, thus distributing weight more evenly. This type of mattress has shown considerable promise in both prevention and treatment of pressure ulcers. Research by Nixon et al. [11] indicated that LAL mattresses are particularly effective in maintaining skin integrity and reducing the occurrence of ulcers in high-risk patients.

Hybrid mattresses combine features of both foam and alternating pressure systems to offer versatile solutions for pressure redistribution. They can switch between static and dynamic modes, providing both the stability of foam and the adaptability of air systems. A comparative study by Brienza et al. [12] found that hybrid mattresses reduced the incidence of pressure ulcers more effectively than traditional foam mattresses and were comparable to alternating pressure systems in terms of effectiveness.

Recent innovations have introduced mattresses with advanced materials and configurations aimed at enhancing pressure redistribution and patient comfort. El-Messeiry et al. [13] developed a mattress incorporating a sponge layer, an air mattress layer, and a paper sheet layer designed to adjust to the patient's weight and provide ventilation with dry air mixed with therapeutic substances. This design showed promising results in increasing the contact area and reducing pressure points, potentially lowering the risk of PUs.

A biomechanical study was conducted to compare four premium mattresses from different manufacturers. The evaluation used two distinct measurements: pressure distribution patterns and the degree of spinal distortion in a side-lying position. The results indicated that one mattress significantly reduced maximum pressure in both the pelvic and thoracic regions compared to the other three mattresses [6]. James W. DeVocht et al. [14] conducted a study measuring interface pressure with healthy volunteers lying on various types of mattresses. They found that Tempur polyethylene-urethane mattresses reduced pressure by 20-30% compared to standard hospital mattresses.

The visco-elastic pattern of foam is essential for its pressure-damping effect. Polyurethane foam supports are suggested for prevention and treatment of PUs. Hence, there is merit in exploring the mechanical characteristics of commercially available polyurethane foams designed for pressure relief in the prevention and management of pressure ulcers..[15]

El-Messeiry et al. [13] developed a novel mattress that incorporates a sponge layer, an air mattress layer, and a paper sheet layer. The sponge and air mattress layers are designed to increase the contact area with the patient's body, adjusting to the patient's weight. An intermediate rubber layer facilitates ventilation by delivering dry air or a mixture of dry air with ozone gas, essential or volatile oils, and/or antibacterial vapors to the areas of the mattress in contact with the patient. Another sponge layer helps to evenly distribute the air beneath the patient's body. The top paper sheet layer is engineered to activate alarms if the mattress becomes wet due to sweating or incontinence.

2.2 Evaluating Comfort and Cost Efficiency of Pressure-Redistribution Mattresses

Comfort

Comfort is a vital factor in the selection of hospital mattresses, as it directly impacts patient well-being and recovery. Various studies have examined the comfort levels provided by different mattress types, including standard foam, viscoelastic foam, air, and gel mattresses [16-18].

Foam Mattresses: Standard foam mattresses are widely used due to their affordability and availability. However, research indicates that they offer limited pressure redistribution capabilities, which can compromise patient comfort over prolonged use. Visco-elastic foam mattresses, on the other hand, have shown better results. They conform to the patient's body shape, thereby distributing pressure more evenly and enhancing comfort [19].

Air Mattresses: Air mattresses, particularly those with alternating pressure systems, are designed to alleviate pressure by cyclically inflating and deflating air cells. Studies have demonstrated that air mattresses provide superior comfort by continuously adjusting to the patient's movements, thus reducing pressure points and enhancing blood circulation [20].

Gel Mattresses: Gel mattresses offer a unique combination of comfort and support. They provide a cooling effect, which can be beneficial in maintaining skin integrity and preventing moisture accumulation, further reducing the risk of pressure ulcers. Patients generally report high satisfaction levels with the comfort provided by gel mattresses [21].

Cost Effectiveness

The cost-effectiveness of hospital bed mattresses is determined by their ability to prevent pressure ulcers relative to their purchase and maintenance costs. The evaluation of cost-effectiveness includes initial investment, durability, and the potential savings from reduced incidence of pressure ulcers [10].

Initial Costs and Durability: Standard foam mattresses are the least expensive option but often need to be replaced more frequently due to wear and loss of support. Visco-elastic foam mattresses are more expensive but offer better durability and longer service life, making them a cost-effective option in the long term [22].

Preventive Savings: Air and gel mattresses, while having higher initial costs, can lead to significant savings by effectively preventing pressure ulcers. The cost of treating pressure ulcers can be substantial, involving extended hospital stays, additional medical treatments, and increased nursing care. By preventing these ulcers, advanced mattresses can reduce overall healthcare costs [23].

Economic Evaluations: Economic evaluations of pressure-relieving mattresses have shown that despite the higher upfront costs, mattresses like air and gel types are cost-effective in the long run. A study conducted on the economic impact of different mattress types found that air mattresses with alternating pressure systems offered the best balance between cost and effectiveness in preventing pressure ulcers[23-25].

To assess the cost-effectiveness of pressure-redistribution mattresses (PRMs) versus standard mattresses (SMs) on emergency room stretchers and beds for preventing pressure ulcers (PUs) in patients admitted through emergency departments, a Markov model was created to track the progression of PUs. Data on the prevalence of hospital-acquired (H-A) PUs, health utility, and costs were sourced from population-based studies [5]

In their findings, Martin van Leen et al. [8] recommended the utilization of a static air overlay mattress in

conjunction with regular repositioning for improved outcomes. They highlighted the efficacy of static air cushions, particularly for patients in wheelchairs, as they minimize maximum contact points.

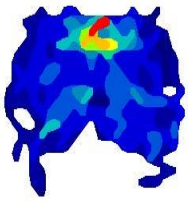
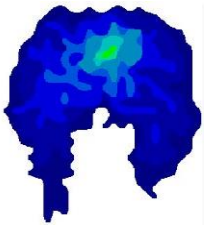
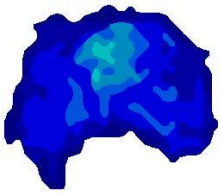
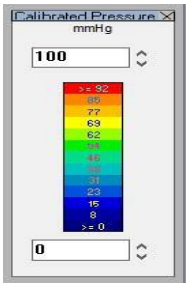
3 Methodology

3.1 Study Design

This study aims to identify the locations of maximum interface pressure on different mattresses and evaluate the comfort of each using the CONFORMat® pressure mapping system. A total of 40 subjects of age group 20 to 60 years, comprising students and staff from the College of Engineering, participated in the study. Of these, 32 were male and 8 were female, all of whom provided informed consent.

Participants were positioned in a supine posture over pressure sensing pad on SHM. Calibrated skin-bed interface pressure profile images were captured for each participant for supine posture, as shown in Figure 1a and 1b. Figure 1a shows the measurement of skin bed interface pressure on SHM with Pressure mat and Figure 1b. İndicates pressure mapping images obtained on CONFORMat®. To minimize measurement error, a 15-second stabilization period was observed before recording the pressure profile. Initial data were collected upon admission to the trial. This data collection shown in Table 1. serves as a basis for proposing an innovative mattress design.

(a) Skin-bed interface pressure measurement on SHM [26]

Standard Hospital Mattress (SHM)	SHM with Silicone Gel pad	SHM with Visco-gel pad	Calibration Scale
			
Skin bed interface pressure at Buttocks (60.58 mmHg)	Skin bed interface pressure over silicone gel pad at Buttocks (49.17 mmHg)	Skin bed interface pressure over Visco-gel pad at Buttocks (36.68 mmHg)	

(b)

Fig. 1 (a.) Pressure mapping in supine posture. (b.) Skin bed interface pressure images on diffrent mattresses by using Takscan pressure measurement system.

Table 1 Comparative of maximum interface pressure and Comfort ratings outcome over the SHM, SHM with Silicone gel Pad and SHM with Visco- gel Pad.

Sr. No.	Skin Bed IP at Std. Hospital Mattress in (mm Hg)	Comfort Rating (Scale 1-5) SHM	Skin Bed IP at SHM with Silicone gel pad layer in (mm Hg)	Comfort Rating (Scale 1-5) SHM with Silicone Gel Pad	Skin Bed IP at SHM with Visco gel pad layer in (mm Hg)	Comfort Rating (Scale 1-5) SHM with Visco Gel Pad
1	54.97	3	51.68	1	44.97	5
2	58.3	1	49.76	4	41.2	3
3	62.64	5	50.95	5	44.2	3
4	67.26	4	44.9	5	38.76	3
5	54.54	2	50.3	3	40.76	2
6	54.54	3	52.18	1	42.26	5
7	67.91	1	51.62	1	36.91	1
8	63.41	1	54.21	3	39.19	4
9	57.94	4	45.59	3	34.58	1
10	57.94	3	45.59	3	37.92	5
11	59.54	5	49.86	4	39.72	4
12	54.99	3	49.17	1	43.91	5
13	59.25	4	46.41	4	38.56	3
14	53.89	4	53.44	3	38.56	4
15	58.3	3	52.12	1	37.15	3
16	62.27	4	52.71	4	39.21	1
17	57.8	3	45.64	4	36.63	1
18	61.56	2	53.64	3	39.36	4
19	59.64	3	53.99	1	39.69	4
20	57.84	3	50.89	3	36.28	5
21	60.52	4	55.58	1	36.2	5
22	52.3	4	48.23	5	38.82	3
Sr. No.	**Skin Bed IP at Std. Hospital Mattress in (mm Hg)**	**Comfort Rating (Scale 1-5) SHM**	**Skin Bed IP at SHM with Silicone gel pad layer in (mm Hg)**	**Comfort Rating (Scale 1-5) SHM with Silicone Gel Pad**	**Skin Bed IP at SHM with Visco gel pad layer in (mm Hg)**	**Comfort Rating (Scale 1-5) SHM with Visco Gel Pad**
23	56.45	1	51.41	2	34.28	4
24	55.46	1	54.57	2	39.63	1

25	56.47	2	55.14	2	40.27	5
26	58.56	1	54.88	3	40.63	5
27	56.24	3	53.65	5	37.73	1
28	58.42	4	51.66	1	39.9	5
29	60.58	1	50.09	4	39.22	3
30	60.8	1	51.48	1	41.49	4
31	54.91	2	49.62	4	41.04	1
32	62.14	2	46.77	1	38.3	4
33	59.06	3	45.91	5	36.94	5
34	59.87	4	53.92	4	41.89	5
35	62.14	2	51.86	3	39.2	1
36	61.19	1	48.22	1	36.68	3
37	62.34	4	45.75	1	37.32	2
38	60.37	4	52.93	4	39.68	1
39	63.84	1	51.96	3	39.83	2
40	57.78	2	51.41	3	39.3	2

3.2 Statistical Analysis of Interface Pressure

After collecting the data, to determine significant differences in skinbed interface pressure between the different types of mattresses a t-test was conducted. The results are presented below and demonstrate that there are statistically significant differences in interface pressure between the SHM, SHM with Silicone Gel Pad Mattress, and SHM with the Visco Gel Pad Mattress.

1. **Descriptive Statistics:**

- **Standard Hospital Mattress (SHM):**
  - Mean IP: 59.10 mm Hg
  - Standard Deviation: 3.47 mm Hg
- **SHM with Silicone Gel Pad:**
  - Mean IP: 50.74 mm Hg
  - Standard Deviation: 3.06 mm Hg
- **SHM with Visco Gel Pad Mattress:**
  - Mean IP: 39.20 mm Hg
  - Standard Deviation: 2.36 mm Hg

2. **t-Tests:**

- **SHM vs. Silicone Gel Pad Mattress:**
  - t-statistic: 10.95
  - *p*-value: 1.85×10−131.85 \times 10^{-13}1.85×10−13

- Interpretation: The *p*-value is significantly less than 0.05, indicating a statistically significant difference between the SHM and the Silicone Gel Pad Mattress.

- **SHM vs. Visco Gel Pad Mattress:**

- t-statistic: 27.87

- *p*-value: 2.31×10−272.31 \times 10^{-27}2.31×10−27

- Interpretation: The *p*-value is significantly less than 0.05, indicating a statistically significant difference between the SHM and the Visco Gel Pad Mattress.

- **Silicone Gel Pad Mattress vs. Visco Gel Pad Mattress:**

- t-statistic: 21.98

- *p*-value: 1.41×10−231.41 \times 10^{-23}1.41×10−23

- Interpretation: The *p*-value is significantly less than 0.05, indicating a statistically significant difference between the Silicone Gel Pad Mattress and the Visco Gel Pad Mattress.

Comfort Responses Summary

Standard Hospital Mattress

Ratings	***Count***
1 (Least Comfortable)	8
2	6
3	10
4	10
5 (Most Comfortable)	6

Mean Rating: (1∗8+2∗6+3∗10+4∗10+5∗6)/40=(8+12+30+40+30)/40=120/40=3.00(1*8 + 2*6 + 3*10 + 4*10 + 5*6) / 40 = (8 + 12 + 30 + 40 + 30) / 40 = 120 / 40 = 3.00(1∗8+2∗6+3∗10+4∗10+5∗6)/40=(8+12+30+40+30)/40=120/40=3.00

Silicone Gel Mattress

Ratings	***Count***
1 (Least Comfortable)	12
2	4
3	10
4	9
5 (Most Comfortable)	5

Mean Rating: (1∗12+2∗4+3∗10+4∗9+5∗5)/40=(12+8+30+36+25)/40=111/40=2.775(1*12 + 2*4 + 3*10 + 4*9 + 5*5) / 40 = (12 + 8 + 30 + 36 + 25) / 40 = 111 / 40 = 2.775(1∗12+2∗4+3∗10+4∗9+5∗5)/40=(12+8+30+36+25)/40=111/40=2.775

Visco Gel Mattress

Ratings	***Count***
1 (Least Comfortable)	8

2	6
3	9
4	9
5 (Most Comfortable)	8

Mean Rating: (1∗8+2∗6+3∗9+4∗9+5∗8)/40=(8+12+27+36+40)/40=123/40=3.075(1*8 + 2*6 + 3*9 + 4*9 + 5*8) / 40 = (8 + 12 + 27 + 36 + 40) / 40 = 123 / 40 = 3.075(1∗8+2∗6+3∗9+4∗9+5∗8)/40=(8+12+27+36+40)/40=123/40=3.075

3.3 Mattress Design

By collecting anthropometric data of Stature, Scapula, Sacrum and Buttock height to locate visco gel pads and air pockets design of mattress is preared. The innovative mattress design includes a numeral 1 of Figure 2 designates first polyurethane foam layer with cylindrical pins for resilience and weight distribution, 2 a second soft polyurethane foam layer with channels 4 and mesh 5, an intermediate water-repellent fabric layer 6, and a third gel-filled mesh layer 7. This design aims to provide proper support, pressure relief, and increased contact area for the patient's body. The intermediate fabric layer channels away sweat and incontinence, keeping the body dry, while the gel layer distributes pressure and provides a cooling effect.

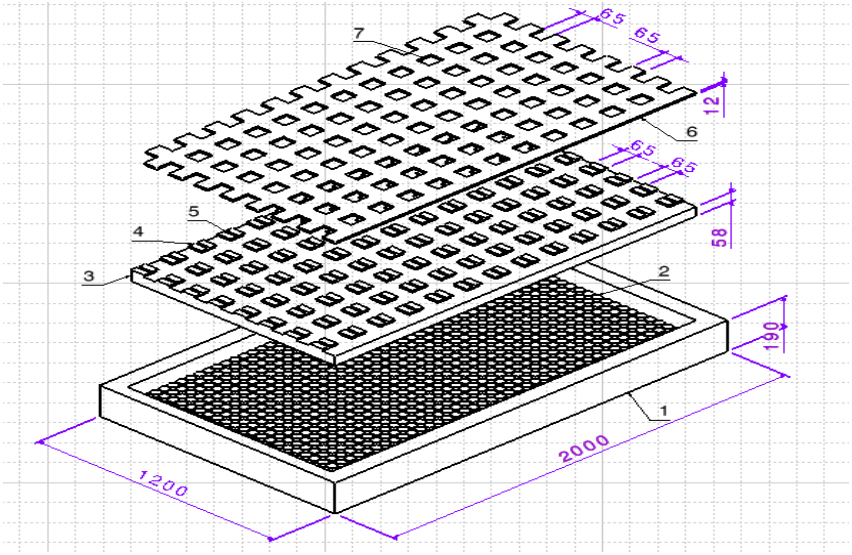


Fig 2 Exploded view of mattress for preventing pressure ulcers

The final model of this design with specification is shown below in Figure 3 and Table 2 respectively.

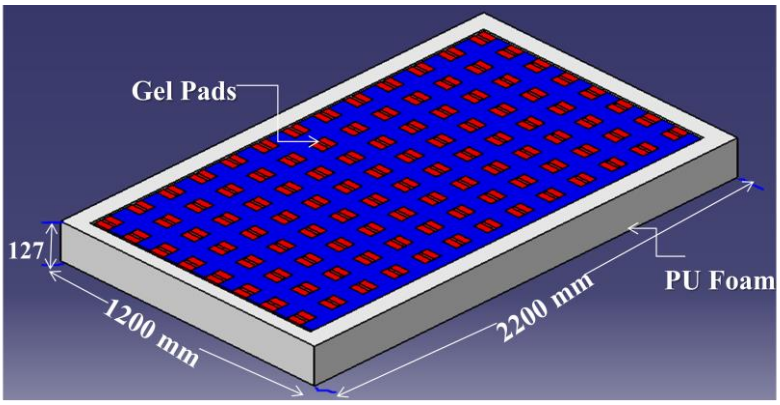


Fig 3 final design of mattress

Table 2 Specifications of final model of mattress

Particulars	Material	Density	L x W x T in mm
Bottom Layer with Cylindrical pins	PU foam	60kg/m3	2200 x 1200 x 127
Middle foam	PU foam	50kg/m3	2000 x 1000 x 76
Top Layer pads	Visco-Gel	80-100 kg/m3	76 x 76 x 10

4 Results

4.1 Incidence of Skin Bed Interface Pressure

Based on the statistical analysis, the Visco Gel Pad Mattress has the lowest mean interface pressure (39.20 mm Hg) and a statistically significant difference in interface pressure when compared to both the Standard Hospital Mattress and the Silicone Gel Pad Mattress. Additionally, the comfort rating is highest for the Visco Gel Pad Mattress (average rating of 3.2).

4.2 Patient Comfort and Satisfaction

Based on the mean comfort ratings, the Visco Gel Mattress has the highest mean comfort rating (3.075), followed by the Standard Hospital Mattress (3.00), and then the Silicone Gel Mattress (2.775). Therefore, the Visco Gel Mattress provides the best comfort according to the data collected from the 40 subjects.

5 Conclusion

The comparative effectiveness of hospital bed mattresses in preventing pressure ulcers varies significantly across different types. While traditional foam mattresses provide basic support, advanced options like, Hybrid mattresses and innovative design which is proposed in this paper continue to push the boundaries, combining various features to maximize patient outcomes. The proposed design will prioritize targeting pressure-susceptible areas rather than addressing the entire body. It will incorporate both high-specification foam and alternate pressure points to redistribute and alleviate pressure, thereby offering greater comfort compared to existing devices. This approach aims to provide enhanced prevention against pressure ulcers by effectively addressing the areas most prone to developing them. Ongoing research and technological advancements are essential to further improve mattress designs and reduce the incidence of pressure ulcers in healthcare settings. Hence proposed innovative design adopting these materials in clinical settings can enhance patient care and reduce the burden of pressure ulcers. Further studies are needed to confirm these benefits in broader patient populations.

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