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A Review on Pressure Ulcer: Aetiology, Cost, Detection and Prevention Systems

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Abstract

Pressure ulcer (also known as pressure sore, bedsore, ischemia, decubitus ulcer) is a global challenge for today's healthcare society. Found in several locations in the human body such as the sacrum, heel, back of the head, shoulder, knee caps, it occurs when soft tissues are under continuous loading and a subject's mobility is restricted (bedbound/chair bound). Blood flow in soft tissues becomes insufficient leading to tissue necrosis (cell death) and pressure ulcer. The subject's physiological parameters (age, body mass index) and types of body support surface materials (mattress) are also factors in the formation of pressure ulcer. The economic impacts of these are huge, and the subject's quality of life is reduced in many ways. There are several methods of detecting and preventing ulceration in human body. Detection depends on assessing local pressure on tissue and prevention on scales of risk used to assess a subject prior to admission. There are also various types of mattresses (air cushioned/liquid filled/foam) available to prevent ulceration. But, despite this work, pressure ulcers remain common.This article reviews the aetiology, cost, detection and prevention of these ulcers.

Keywords: Pressure ulcer, Tissue necrosis, Cost, Risk Assessment, Detection, Prevention, Body Mass Index

Introduction

The modern healthcare industry is facing a major challenge to prevent pressure ulcers (PU) in the human body. In UK, approximately 412,000 people develop pressure ulcers each yearin hospitals while lying on beds or sitting on chair for longer periods. This costs the UK hospitals approximately £1.4-£2.1 billion a year (nearly 4% of NHS budget) and has been identified as one of the most serious problems in UK's healthcare industry[1][2]. People with mobility impairments, spinal cord injury, head trauma or multiple scleroses (MS) are most at risk of pressure ulcers [3][4], but elderly people are more prone to develop pressure ulcer as well, and their numbers large. PU occur where soft tissues are subject to continuous loading and, as a result, blood circulation in soft tissues becomes low, oxygenation falls, leading to tissue necrosis and, in turn, pressure ulcer (see Figure 1).The subject's physiological parameters (age, body mass index) along with the support surface material (mattress) have significant roles in the genesis and risks of pressure ulcer formation. Immobility leads to a pressure at the interface of the skin and support surface material, so called interface pressure without the usual relief from movement. The tissue underneath the skin has reduced blood flow and oxygenation, leading to tissue necrosis (cell death). So it is very important to relieve the interface pressure in a timely way.

Figure 1: A subject with heel pressure ulcer [5]

Ulcers can form at a number of areas on the body according to the pressures on them with recumbency and their resilience, depending on skin thickness, blood flow, underlying bone etc.

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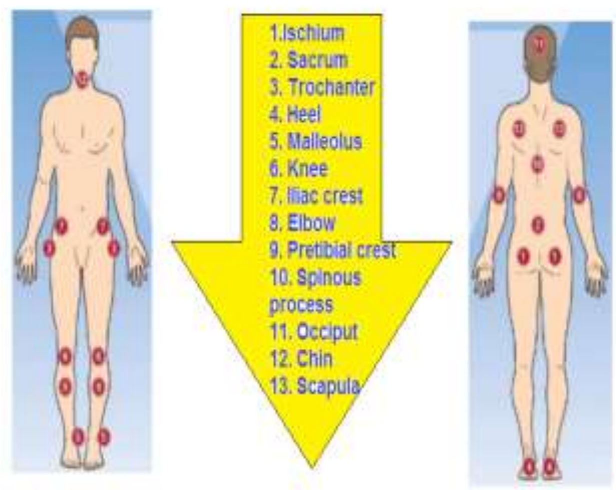

Figure 2: common pressure points in human body [6]

Aetiology of pressure ulcer

According to the European Pressure Ulcer Advisory Panel (EPUAP)[5], Pressure Ulcer can be classified in four different stages such as:

Stage 1:Non-blanchable erythema refers the intact skin with non-blanchable redness of a localized area usually over a bony prominence. The reddened area remains red after the pressure is relieved. The area may be painful, firm and warmer as compared to adjacent tissue.

Stage 2: Partial Thickness, in this stage a shallow open red pink ulcer is visible due to the partial thickness loss of the dermis. It can also be represented as an open serum-filled/sero-sanginous filled blister. A shiny/ dry shallow ulcer results without any slough or bruising.

Stage 3: Full thickness skin Loss: In this stage the ulcer worsens, with full thickness skin loss and tissue necrosis results in skin and subcutaneous tissue but not through bone tendon or joint capsule.

Stage 4: Full thickness tissue loss: Full thickness tissue loss with exposed bone, tendon or muscle. Slough may be present and there may be undermining and tunnelling. The depth of Stage 4 pressure ulcers varies by anatomical location. Stage 4 ulcers can extend into muscle and/or supporting structures (e.g., fascia, tendon or joint capsule) making superimposed infection, osteomyelitis or osteitis, likely, see Figure 3.

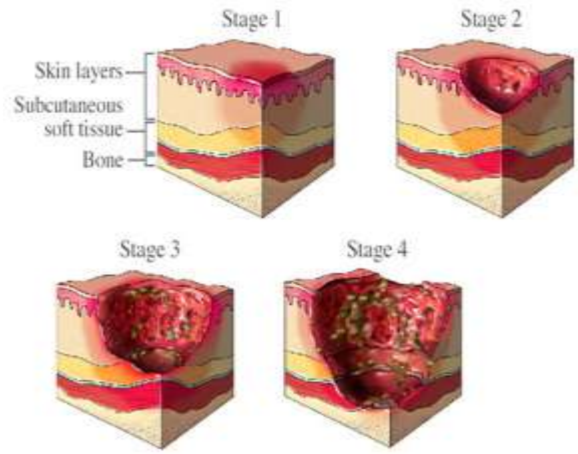

Figure 3: Different stages of pressure ulcers according to EPUAP [5].

The aetiology of pressure ulcer also depends on other measures such as the properties of skin, subject's body mass index, age, blood flow in tissues. These measures are discussed below more elaborately.

A. Biological Properties of skin & soft tissue

The skin is the outer cover of the human body and offers strength and stiffness to oppose external mechanical loading as well as insulation, sensation and temperature regulation. In order to perform these tasks, it is very important to have mechanical stability and mechanical flexibility of skin. The epidermis is relatively non-vascular [7] and its main function is protection. The dermis contains the blood vessels. Within these layers lie large amounts of collagen, a protein which provides much of the body's structural support and which holds our body together with strength and elasticity [8]. The subcutaneous fat layer acts in part to allow some shearing forces and to cushion forces directly applied, though this subcutaneous layer does not have major tensile strength. For disease like pressure ulcers, the collective response of all the skin layers is important. Figure 4 shows the skin overview with different layers.

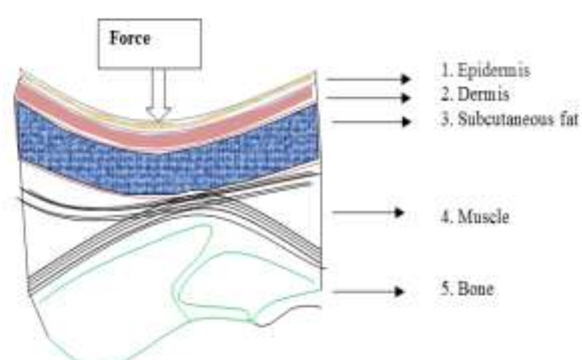

Figure 4: Schematic of soft tissue Layers

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The pressure distributing properties of muscle are good[9] but the subcutaneous tissue and particularly muscle is more susceptible to pressure induced injury than the epidermis[9], [10]. External forces have differing effects on the different tissue layers, which in turn have differing resilience. And of course some body parts are more susceptible because of the forces they meet and because of the relation between skin, subcutaneous tissue and bone. In additionas we age the collagen content of the dermis is decreased and elasticity is loss, leading to less resilience to pressure. [11].

B. Subject's body mass index and age

Body mass index has relevance in the development of ulcers, since these are more likely to occur in areas where there is little tissue and fat between the bone and skin. If a person is malnourished, there is also less cushioning between the bony surface and the skin [12].Another factor is age, since with this; Also the skin gets dry. Patients aged over 65 are more susceptible to develop pressure ulcers and it has a great deal of correlation with the skin [13].The changes in skin function and structure mentioned above, along with risks that occur in overall health and functional capability can put elderly patient at a high risk for developing pressure ulcer.

C. Blood flow

Blood flow is a major factor in the formation of pressure ulcers. When it is reduced, oxygenation to the tissue falls. Blood flow, in turn, relates to the patient's systemic blood pressure since once local pressure in a tissue exceeds arteriolar pressure, blood flow to that particular region stops[14][15]. This is known as "localized ischemia" [16]. An important factor in the skin is the rate of blood flow in different areas of the body. For example, sacral blood flow is higher than over the gluteus maximus[17][16]. This is important because when blood flow is decreased from an increase in external pressure there is more damage to the sacral; thus correlating to more incidences of pressure ulcers in the sacral region than the gluteus maximus[16].Tissue below the skin breaks down due to anoxia (the lack of oxygen) and lack of blood flow, see Figure 5.

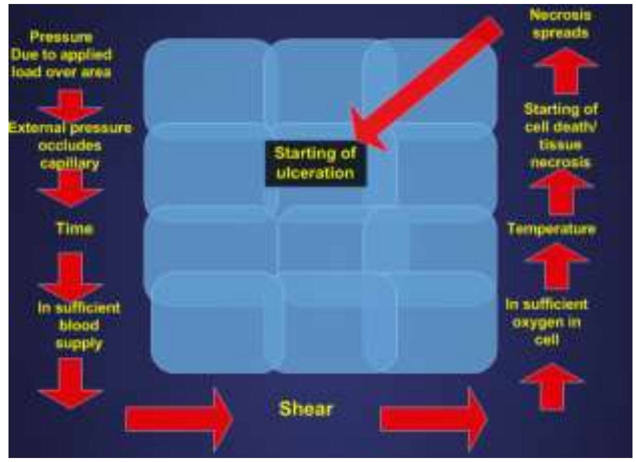

Figure 5: Pressure ulcer development over time.

The Economic impact of pressure ulcer

A report by Peter J Franks[18]showed that a hospital would spend €901,000 to €1,614,000 per year. If the prevention strategy in the care of patients is included then the cost will be increased at €3,794,000 [18][19]. The standard cost per person for the different stages of pressure ulcer has been estimated at €1,489 for stage I, €6,162 for stage II, €10,238 for stage III and €14,771 for stage IV. In UK, the number of people who develop PU annually has been estimated as 140,000 for stage I, 170,000 for stage II, 50,000 for stage III and 50,000 for stage IV. In European Union (EU) the total annual cost of pressure ulcers was estimated yearly at €214 million (stage I), €1,047 million (stage II), €544 million (stage III) and €670 million (stage IV). In Australia it is established by a research that a subject with pressure ulcer requires extra 4.31 days in hospital compared to other patients and the cost of this extra days were estimated as AU$28 million (€170.7 million) yearly[20]. In USA pressure ulcer cost the healthcare industry US$11 billion yearly with the average cost for each subjectUS$43,000. Also the length of stay in hospital is 3 times higher for the subject with pressure ulcer. Also around 14.8% of total population in USA develop pressure ulcer whereas around 20% of people develop pressure ulcer in Europe[21][22]. Figure 6 shows the population affected by pressure ulcer globally per year. Apart from the increased morbidity and having patients at risk of hospital based infections from extended stays in wards, PU add a huge economic cost to society.

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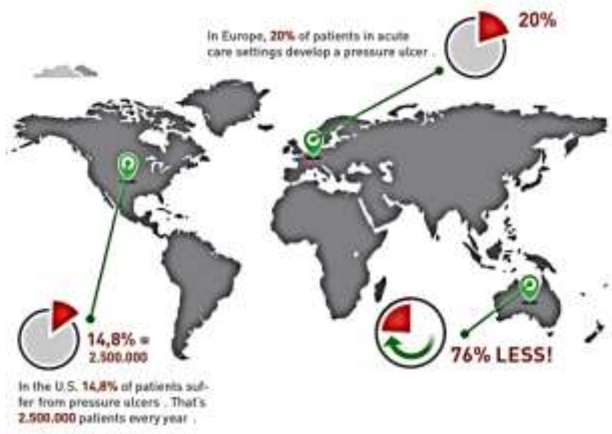

Figure 6: Worldwide population affected by pressure ulcer [22]

Pressure ulcer Detection Systems

Given these clinical and economic imperatives, detection and prevention of PUs are of major importance. Prevention methods have focussed on risk factors and predictive models, whilst early detection has involved systems to measure pressures on patients' skin in vulnerable areas. These systems are either capacitive or piezoresistive and they measure external force only. Also load cell sensors, Carbon Nano coil (CNC), Metal strain gages are available for detection purposes. These technologies have both advantages and disadvantages, e.g. capacitive pressure sensors are susceptible to electrical interference due to its high impedance,metal strain gauges needs supplementary configuration to identify force[23].

In (Yip, M. et al., 2009)capacitive sensors are used to measure the external forceon the human body. The change of capacitance occurs over a small distance of place due to a separation of two conductive plates [24]. An example of capacitive pressure sensing established by Yip, M. is shown in figure 7.

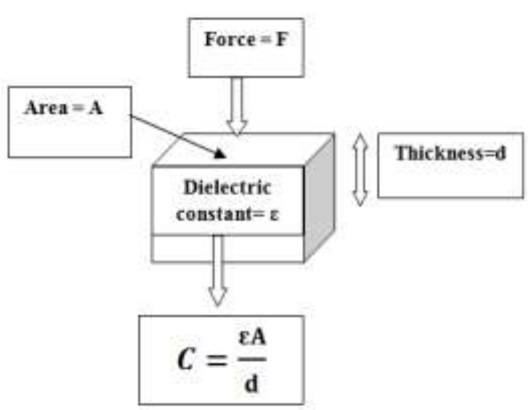

Figure 7: Parallel plate capacitor model with variable capacitance due to modulation of the dielectric thickness by the applied pressure [24]

In figure 8, a schematic of capacitive sensor array is shown (described by [24]. The capacitors are arranged in 11 by 9 arrays. Each unit capacitance $C_{x\,y}$ in row x and column y depends on the pressure applied there. The array is scanned in every 81ms at a sampling frequency of 12-HZ. A 16-bit analogue-to-digital (A to D) converter is used to obtain results. The columns are multiplexed by using one 2:1 multiplexer per column. An array of capacitive pressure sensors is located under the patient's bed. The sensing is done by an analogue device. A low power microcontroller controls the measurement sequence. The digitized data is then transmitted to a computer via a USB interface using a chip. A Graphic User Interface written in visual basic is used to plot the data in real time and post processing is done in Matlab. In order to interface the electronics with the sensor sheet, a USB-powered PCB was designed and used.

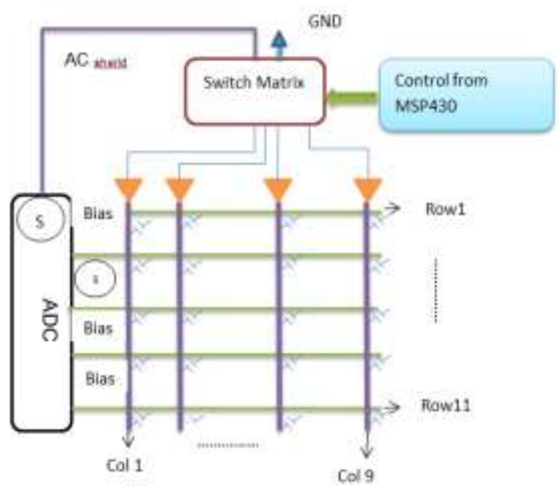

Figure 8: Capacitive sensor array [24]

Though the hysteresis of the capacitive system is recorded >10% but the limitation of this type of design includes sensor to sensor variations and drifting. Periodic re-calibration is required for individual sensor to overcome the drifting. Moreover, the wearing is complex and the power consumption is high in this type of design. Also this research does not show individual pressure induced in tissue and support surface.

Abraham et al, have designed a low cost, disposable mattress for non-invasive sleep and movement monitoring, see Figure 9. cPaper which is a nonwoven material is used to design the pressure sensing array using capacitive principles [25].The conductivity of a single ply cPaper area can be controlled by loading

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carbon fibres at different concentrations onto the base area.

Figure 9: 8x8 matrix pressure mat tile with each element 5 mm wide and 15cm long [25]

In order to design the top electrode, a width of 5mm with a separation of 5 mm cPaper strips is used for the sensor. The bottom column is same as the top. When the pressure is applied, the dielectric material separates the capacitor plates and the capacitances change due to the displacement of electrodes. The data processing and results are obtained using *LABVIEW* software. This type of prototype includes a large scale fabrication process and therefore, it is not suitable for force calculations.

Disadvantages with capacitive pressure sensing technologies are:

- The capacitance changes nonlinearly with diaphragm displacement.
- Sometimes capacitance is too large for the fractional change but absolute change is too small and that indicates a caution in designing the circuit.
- The impedance at the output is very large and that can cause interference to the circuit.

Piezoresistive technologies were used to measure the pressure level on the human body [26]. If the pressure is applied to a surface it produces a deformation in the material. A wireless battery less piezoresistive pressure sensing system is shown where sensing system adjusts with Radio frequency Identification (RFID) operation principle. The system comprised with force sensing resistors, transponder devices, and a monitoring reader system. The force sensing resistors are designed into an array format to measure the pressure distribution across an aperture. In order to signal multiplexing, a switching unit was also included and resistors were connected to that switching unit. The pressure information in the format of resistance values was fed into the transponder device to be converted into frequency shift information. A pressure measurement system and mechanical design of the (Polydimethylsiloxane) PDMS was also included in that design. Figure 10 represents the architecture of a piezoresistive pressure sensing technology which was used in [26].

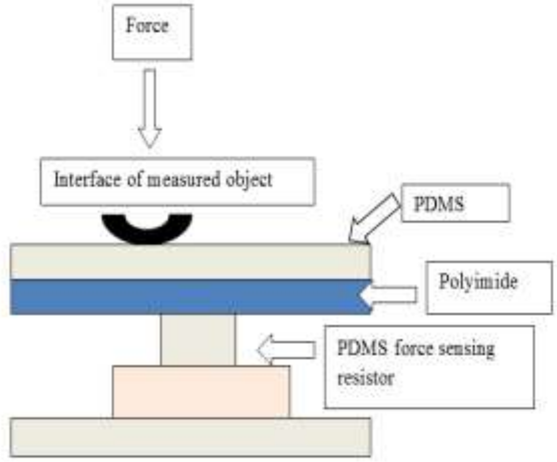

Figure 10: Piezoresistive pressure sensing technology [26]

When a force is applied directly on top of the sensing area of the force sensing resistor, the force will be converted into pressure that is defined by the buffer PDMS structure. This type of design has many advantages such as low cost, high mechanical stiffness, high sensitivity, and small in size.

In [27], Stain gauge technology to detect pressure ulcer is shown but this type of technology is not suitable in some instances as the sensors need to be mounted on the patient's skin. Strain gauges are mostly structured into load cells. A load cell is a mechanical support for a system with strain gauges connected to its internal surface. It measures the strain and therefore the force applied to the structure. As load cells are constructed with strain gauges, care must be taken not to break the connection between the gauge and strained surface. Disadvantages with strain gauges are:

- Small variation in resistance when a force is applied to the interface surface.
- Sensitive to temperature (Resistance changes with temperature)
- Long wiring makes the overall system complex.
- Compared to piezoresistive sensors strain gages have lower sensitivity.

Pressure ulcer Prevention Systems

Various technologies are available to prevent pressure ulcers by distributing the force exerted on specific problem areas, or by devices which move the patient after a set period of time. These solutions do not come with feedback system for each patient's specific contributing physiological factors, such as pressure exerted or moisture content of the sample area. However another disadvantage is that these methods are meant purely for prevention based on time rather than

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prevention based on of physiological factors. Although these prevention technologies provide improvements for the existing treatment of pressure ulcers, none have been accepted as a standard of care globally. Body support surfaces can be categorized into two types; static and dynamic. Static body support surfaces are mainly low tech constant low pressure (CLP) systems [28]. These are classified as foam, air, gel and water mattresses. Furthermore, foam mattresses are classified into two categories such as cold foam mattress (memory less) and viscoelastic foam mattress (also known as memory foam mattresses).

Cold foam (also known as conventional foam) mattresses are made of polyether foam[29][30]. This is elastic foam consisting of many very small closed air cells. After compression it recovers very quickly to its original shape.

Viscoelastic foam mattresses (memory foam mattresses) are also made from polyurethane, but are generally less springy and "remember" the shape of patient's body. This type of mattresses has been used in many pressure ulcer prevention research [31][32].
The advantages of using such kind of mattresses are:

- Strongly reduces the pressure by increasing the contact area between the body and the foam.
- Improves blood circulation by increasing the release of pressure.
- Increases the comfort and stability of the patient.

Viscoelastic foam is characterized by its slow recovery after compression[33]. If a weighted object (e.g. human body) is placed on viscoelastic foam, the foam gradually conforms to the shape of the object, and after the weight is separated, the foam slowly returns to its initial shape. It can also dampen vibration and absorb shock; some can take up to 90% of impact [34][35]. This unique physical characteristic of viscoelastic foam has led to its popularity in healthcare industries for those with impaired mobility, for instance in wheelchairs or hospital beds. Viscoelastic foam mattresses are able to adapt to the shape of the human body and in doing so can distribute pressure over the whole surface very efficiently. Pressure-mapping equipment can be used to analyse the level of weight distribution; some viscoelastic foam manufacturers perform these tests to predict how well the foam might act to reduce pressure.

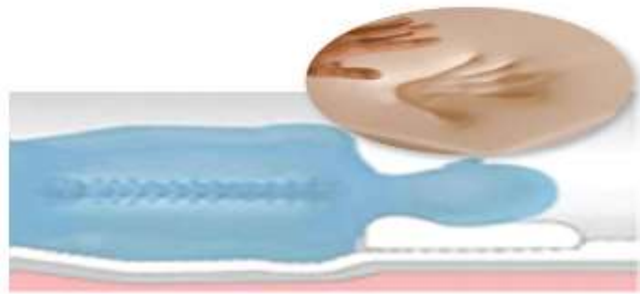

Figure 11: Memory Foam (viscoelastic) [33]

A comparison between a conventional foam and viscoelastic foam was done by [35] where it was shown that viscoelastic foams are more suitable for reducing pressures.

The air filled mattress (AM) is also a useful mattress for preventing pressure sores [36][37][38][39][40]. This type of mattress has a series of bladders which are filled with air. These bladders are, in turn, divided into 6 different zones to distribute pressure, with each zone programmed individually. A delay of 3-5 minutes is created to make automatic adjustments to air volumes. Air-filled mattresses are usually bulky and only required in a critical care setting.

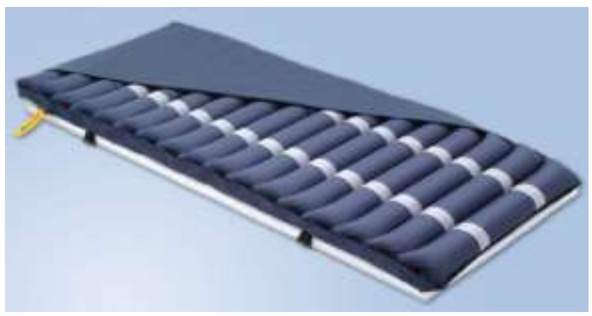

Figure 12: Air filled mattress to assist wound healing and treat pressure ulcers for very high risk users. (EPUAP ulcergrades I to IV) [36]**.**

Risk Assessment Scales

Three risk assessment scales currently used by the health-care professionals are only to predict the PU risk type (e.g. low risk/ at risk/ high risk/ very high risk). These are Norton, Braden and Water-Low scales. These scales are used prior to subjects admission into hospital [41][42]. But none of these scales can be used in real time (e.g. when subject is bed bound or chair bound for a long time).All three risk assessment scales are described below.

A. Norton Scale

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The Norton Scale is the first tool for assessing pressure sore risk identification. The main objective of Norton scale was to assess geriatric population[43][44]. This scale has five criteria: physical condition, mental state, activity, mobility, and incontinence. Each criterion is scored from 1 (very bad) to 4 (good)[45]. The highest score is 20. Initially subject with a score of 14 or less was considered as at risk but in 1980, the cut-off was changed to 15 or 16[46].

B. Braden Scale

Braden scale was the outcome of a study conducted in United States [47]. This assessment scale was developed based on the causes of pressure ulcer and was considered as a consistent tool for the nurses [48]. Braden scale has six criteria: Activity, skin moisture, mobility, friction, nutrition and shear. Each criterion is scored in between 1 to 4. The total score was added at the end. The lower the score, the higher the chance of the subject developing a pressure ulcer. The cut-off was set to 16 to categorize subject at risk of developing PU. But other studies [49][50] show the cut-off was changed to 18 for elderly subject. But this scale does not consider subjects physiological information, tissue malnutrition (organ failure, smoking), neurological deficits (Diabetes, Multiple Sclerosis).

C. Water-Low scale

The Water-Low scale was developed in 1985 [51][52][53] in a UK hospital. This scale is considered as more comprehensive compared to other two assessment scales. A Water-Low scale includes subject's physiological factors such as age, weight, and sex along with tissue health, skin type, and subjects neurological deficits. The scoring for this scale is from 1-8 for different factors. Finally scores are added and based on the score, risk is predicted. A score of 10 to 14 indicates at risk, 15-19 as high risk and above 19 is very high risk. The scoring values vary from factors to factors. The subject's gender scores 1 for female and 2 for male, whereas neurological deficits are scored as 4-6.

Among all these three scales, Water-Low scale is more subject information oriented because it takes subjects physical parameters such as BMI, age into consideration along with tissue factors, neurological deficits and skin conditions.

A Proposal of PU Detection and Prevention Model

Pressure ulcer is the result of subject's physiological parameters and body support surface interaction. Although there are several technologies available to detect pressure ulcer, none has been adopted as a standard detecting procedure for healthcare. This is equally true for prevention techniques. Risk assessment scales are used as a pre-admission tool to assess the risk of pressure ulcer formation but currently there is no integrated risk assessment tool with prevention systems. Also, the current alternating pressure (AP) mattress systems do not support patient specific requirements. So there is a gap between detection and prevention techniques. An integration of detection system together with prevention system would be a significant advance for healthcare industries. A proposed block diagram integrating the above ideas is shown in figure 13.

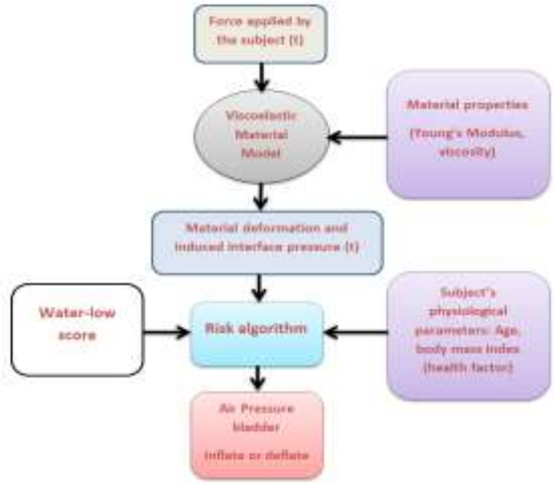

Figure 13: Pressure ulcer detection and prevention model

The block diagram shows the underlying concepts of both detection and prevention systems. The model includes Water-Low score to characterise the physiological parameters of subject's risk factor combined with interfacial pressure at the support surface.. Implementation of such a model would allow detection and prevention at the same time. Moreover, the risk assessment will be subject-specific and can be dynamically monitored and controlled. The currently existing systems do not consider the effect of surface material but they directly measure the applied pressure and are considerably expensive and cumbersome to use. In the proposed architecture the ulceration detection and prevention would be automatic based on mattress properties. By integrating support surface characteristics with human risk factors it will provide patient-specific care for automatic detection. The interface pressurecalculations is based on, material's Young's modulus and viscosityof the mattress or support surface. This, combined with subject's physiological parameters using Water-Low score, will provide actual risk factor. This will allow identifying harmful pressure for individuals and the risk of ulceration in real-time. Based on the pressure level (detected by the threshold interface pressure) the AP mattress (prevention system) will inflate or deflate. This will relieve harmful pressure at the skin surface and subject will have continious blood flow.

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These ideas have been developed in a graphic user interface (GUI) as shown in figure 14.

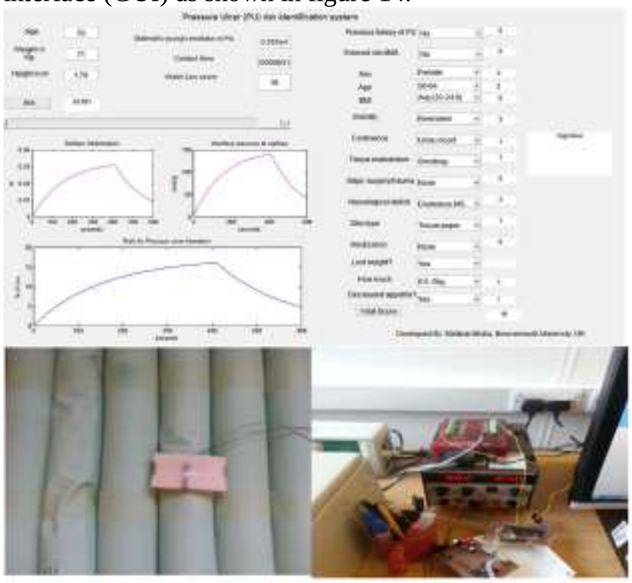

Figure 14: A proposed implemantation of detection and prevention module

Conclusion

Pressure ulcers are very painful for patients, and affect their quality of life. They also are very costly to society. In this article, a review has been conducted on aetiology, cost, detection and prevention techniques along with risk assessment scales of pressure ulcer. At present there are systems that predict PU risk, and pressure beds to reduce the chance of a PU or enable treatment of one once developed. But no system integrates individual risk to drive pressure bed parameters, and no mattress measures pressures in individuals to compare with their risk. Our proposal is to develop a more accurate risk analysis tool and then use this to set the parameters on an intelligent air bed to inflate and deflate according to individual patient need. By measuring pressures in the bed at the patient interface it could also use real time patient feedback to drive its cycles of inflation and deflation. . The aim of this review has been to identify the requirements of an ideal PU system and propose some new design ideas that could integrate between risk stratification, prevention and then to improve treatment in a manner tailored to individual patient profiles.

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