Modelling of Pressure Ulcer (PU) Risk Prediction System

Mahbub C Mishu
Faculty of Science and Technology
Bournemouth University
United Kingdom
Email:mmishu@bournemouth.ac.uk

Jan Walter Schroeder
Faculty of Science and Technology
Bournemouth University
United Kingdom
Email:jschroeder@bournemouth.ac.uk

***Abstract*—Human skin deformation occurs due to external loading. As a result, blood flow in soft tissue becomes low and also the oxygenation decreases. Tissue under continuous loading results in tissue necrosis and leads to pressure ulcer (PU), also known as bedsore, decubitus ulcer, and ischemia. The amount of external load applied to the body support surface is associated with a subject's BMI (body mass index). Therefore interface pressure (IP) at the skin and the surface is the result of a subject's physical and support surface properties. Interface pressure increases, the blood flow decreases and a subject starts developing stage-1 pressure ulcer. Previous research suggests that interface pressure of 32 mmHg (4.26 kPa) can cause PU, but there is no strong evidence to show at what time that pressure is reached. Also interface pressure changes from subject to subject due to their body compositions. Three risk assessment scales are available to predict overall risk of PU formation. But none of these scales take interaction of body support surface materials into account. Also these do not provide any information at which area a subject is at risk of PU formation. In this work a study is presented where external load at different bony areas are measured using 11 volunteers. By measuring the external load for 11 subjects (age:33 ± 7 yrs and BMI:25.04 ± 3.01 kg/m^2) at different bony areas, the relationship with the total body weight was identified. A mathematical model is proposed to predict the risk of PU formation combining the Waterlow risk assessment scales for bony areas and a graphic user interface to predict this is discussed.**

***Index Terms*—Pressure Ulcer; BMI; Waterlow Score; viscoelastic material; relative risk; Risk Prediction;**

I. Introduction

Preventing and treating pressure ulcer (PU) has become a global challenge for today's healthcare industry. Mostly people with mobility impairments, spinal cord injury, head trauma or multiple sclerosis develop pressure ulcer [1], [2]. Also, people in coma or people in long surgical procedure develop pressure ulcer [3], which is also known as bedsore, ischemia, and decubitus ulcer. It has become a very expensive treatment now a days and also has a huge impact on patients quality of life. In the United Kingdom, 412,000 people develop PU yearly and £2.1 billion is spent within the NHS [4], [5]. This amount is almost 4% of the total annual budget of the NHS. In Australia, the annual costs of treating PU is AUS$350 million [6] and in U.S.A, the average cost of treating PU for individual is US$43,000 [7]. Also According to the European Pressure Ulcer Advisory Panel (EPUAP), the average length of a stay in a U.S. hospital is 3 times higher for patients with PU. These figures show how important it is to develop a risk predicting tool for preventing PU. Pressure ulcer develops when someone is lying or seating on a surface for a long period of time without any movement. Due to not having any movement, the interface pressure between the surface and the skin increases as a result the blood flow in soft tissue decreases [1], [5], [8]. This leads to form pressure ulcer in a subject's body. Also it occurs due to a subject's physiological parameters such as body weight, height. Pressure ulcers mostly develop at bony areas (43% at sacrum, 11% at heel) compared to soft muscular area)[9], [10]. Figure 1 shows the frequency of pressure ulcer occurrence in the human body.

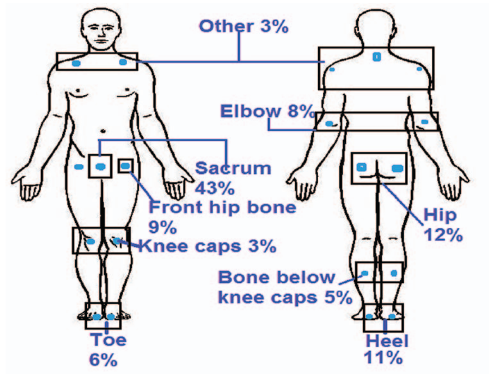

Fig. 1: Common pressure points in the human body with the frequency of PU occurrence

II. Aetiology and Current Risk Assessment Scales for PU

Pressure ulcer occurs due to tissue breakdown in skin [8]. It occurs when people are immobile and subjected to prolonged external loads. Due to this loading, the blood flow and the oxygen supply become poor to the soft tissues [5], [1] and that leads to tissue necrosis [1], [2]. Studies suggest a pressure higher than 32 mmHg [1], [2], [8] applied to the skin can be sufficient to damage soft tissue. However, there is no strong scientific evidence available showing at what time a subject will reach that pressure value. According to

TABLE I: Different stages of Pressure Ulcer.[11]

stages	Description
Non-blanchable erythema	Red spot is visible in skin and it remains red after the external pressure is relieved
Partial Thickness	A shallow open red ulcer becomes more visible due to loss of dermis and the wound becomes open filled blister
Full thickness skin Loss	Ulcer gets worse with full thickness skin loss and results tissue necrosis
Full thickness tissue loss	Ulcer reaches to the bone, tendon or muscle

TABLE II: Existing three risk assessment scale for PU.[12], [13], [14], [15]

Scale	Criteria of assessment	Scoring method and risk type
Braden	Sensory perception Moisture, Activity Mobility, Friction, Nutrition	Additive Total score <=9: severe risk Total score 12-13: high risk Total score 13-14: moderate risk Total score 15-18: mild risk
Norton	Physical & mental conditions, activity, mobility, incontinence	Additive >18: Low risk 18-14: Medium risk 14-10: High risk <10: Very high risk
Water-Low	Previous history of PU Age,sex,BMI, incontinence, mobility, tissue malnutritions, neurological factors, skin type, medication, surgery history	Additive <=9: low risk 10+: at risk 15+: high risk 20+ very high risk

the European Pressure Ulcer Advisory Panel (EPUAP), there are four different stages of pressure ulcer and the stages are briefly summarized in Table I. To prevent ulceration in the human body, risk assessment scales are widely used in hospitals. These scales show the types of PU risk (e.g. low risk, at risk, high risk, very high risk). Currently three such scales are available and they are: Norton scale, Braden scale and Waterlow scale. These scales are briefly summarized in Table II. Among these three scales, Water-Low scoring system uses subject specific information and takes subject's physical parameters such as BMI (body mass index), age and sex into consideration along with the tissue factors, neurological deficits and skin conditions. Therefore, this scale is incorporated within the developed risk prediction system.

Formation of PU is a result of external load applied to the support surface area. When a subject is lying on the support surface, the total weight is distributed throughout the surface. Therefore, it is very important to know how much external load is applied at different areas (e.g. heel, sacrum). Also it is equally important to know the relationship of external load at different points with the total body weight.

Fig. 2: Calibration of sensor using mechanical rig

Fig. 3: Measuring external load at the right heel

III. Measuring external load at bony areas

In this section the measurement of external loads at different bony areas for 11 subjects are shown. In order to measure load at different bony areas(heels, sacrum, elbow), Flexiforce sensors (Model: A201) were used. 11 subjects with age:33 ± 7 yrs and BMI:25.04 ± 3.01 kg/m^2) were selected and load was measured at different bony areas for each individual. The objective of such experiment is to identify the relationship of external load at one location with total body weight of any subject. Later, these relationships are used to develop the PU risk prediction model. The sensor calibration was completed by using a mechanical rig. During the rig test, known load was applied to the top of the rig and the output from the sensor was measured [11]. After the sensor calibration, four force sensor were combined to a single sensor array to increase the sensor contact area. Each force sensor has a contact area of $0.00000631m^2$ (6.31 mm^2). This area is very small and not suitable for the external load measurements. This is why the integration of four sensors was done. Then the contact area becomes 0.00002524 m^2 (25.24 mm^2). Figure 2 shows the calibration of flexiforce sensor. Figure 3-5 shows the external load measurement procedures for one volunteer along with the sensor. The subject's physiological information along with results from the experiments are given in Table III and IV.

During the experiments, participants were asked to lie down on a viscoelastic mattress (flat posture). Also they were

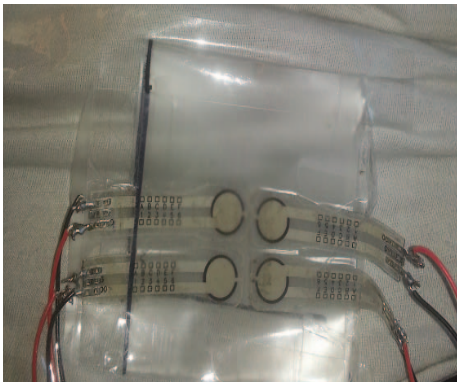

Fig. 4: Sensor array setup on a support surface

Fig. 5: Measuring external load at the right elbow

Area	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
% of total weight at right heel	6.2	5.8	6.3	5.7	6.5	6.1	6.4	6.2	6.4	6.3	6.0
% of total weight at left heel	5.8	6.5	6.7	6.1	6.7	6.6	6.4	6.0	6.4	5.8	6.4
% of total weight at right elbow	3.6	2.8	3.5	2.7	2.8	2.7	3.2	3.2	3.5	3.4	3.4
% of total weight at left elbow	3.2	2.9	3.2	2.7	3.0	3.0	3.0	3.0	3.65	3.2	3.4
% of total weight at sacrum	10	10.2	9.8	9.8	10	9.6	10.2	9.8	10.1	9.9	9.7

TABLE IV: Relationship of bony areas with total body weight at different bony areas

Location	% of total weight
Right heel	6.17
Left heel	6.30
Right elbow	3.17
Left elbow	3.11
Sacrum	9.92

asked to not move for the time of the experiment. Thus the external loads at different bony areas were measured and the relationship with total body weight was established. The relationships are given in Table V. These information were used to develop the risk prediction system later.

IV. Development of PU risk prediction system

Pressure ulcer is the result of subject's physiological properties and support surface material's property. In this section, a risk prediction system is developed. For this, relationship between subject's ages, BMI with interface pressure [16], [17], [18] are considered. Based on the relationships, a mathematical model is developed where a subject's information can be entered as input information and the system will predict percentage of risk at different bony areas. The main objective of developing such a system is to predict the risk of forming stage-1 pressure ulcer and by knowing the risk, a subject can be saved from developing PU. To develop the mathematical model, relative risk predication algorithm is considered [19], [20]. Also to predict risk at any bony prominence, percentage of the total weight data (shown in table V) is used. The algorithm is modified as per the relationship between ages, BMI with interface pressure and it provides the risk of PU at bony areas. Figure 6 shows the flow chart for risk prediction model.

TABLE III: Subject's physiological information

ID	Age	Weight in Kg	Height in m	BMI in kg/m^2
A1	26	76.4	1.7	26.44
A2	28	75	1.62	28.58
A3	30	70	1.78	22.03
A4	31	75.8	1.74	25.04
A5	31	83	1.79	25.90
A6	33	74.4	1.73	24.86
A7	35	70.2	1.7	24.29
A8	35	73	1.73	24.39
A9	36	55.7	1.54	23.49
A10	40	76	1.7	26.30
A11	40	66	1.61	25.46

A. *Relative risk prediction algorithm*

Relative risk prediction algorithm [19], [20], [21], [22] has been used in biomedical research to measure the risk. This type of algorithm consists of multiple parameters and it provides the odds of risk. Each parameter is converted into a associated risk score and finally the risk is calculated. It uses a general linear modelling system. Previously it is used to identify the risk of lung cancer development and dermal wound exposure among two groups of patients [23], [24].

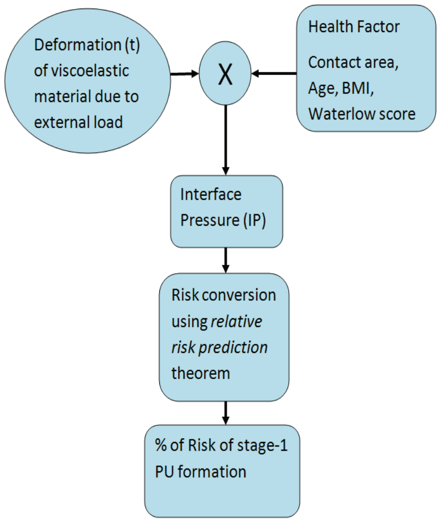

Fig. 6: Flow chart for the risk prediction model

$$O_R = C_1 * (\frac{P_1}{max(P_1)}) + C_0 * (\frac{P_0}{max(P_0)}) \quad (1)$$

$$R_R = \frac{O_R}{(1 - P_0) + (P_0.O_R)} \quad (2)$$

Where P_0 and P_1 are the incidence of the outcome of the non-exposed and exposed group respectively; O_R is the odd ratio and R_R is the relative risk. To calculate the risk of PU formation, PU risk factors (physiological and support surface properties)are considered. Then the relative risk prediction algorithm is used and thus PU risk prediction model is developed(shown in next section).

B. Mathematical modelling of PU risk prediction

The following equations are developed to predict the risk of PU formation.

$$R_f = \frac{\varepsilon(t).H_f}{0.01} \quad (3)$$

Where R_f is the risk factor of PU for any individual, $\varepsilon(t)$ is the viscoelastic material deformation in m. H_f describes the health factors (age, BMI, and Water Low score). The support surface deformation is in m. So to make the R_f a unitless number , it was divided with 0.01. Thus R_f becomes a unitless number.

$$H_f = [a.(\frac{ra}{max(ra)}) + b.(\frac{rb}{max(rb)}) + c.(\frac{rw}{max(rw)})] \quad (4)$$

where a<1,b<1 and c<1 and ra, rb and rw is the converted values of age, BMI and Water Low score (shown in Table VI,VII and VIII). To obtain the deformation of viscoelastic material $\varepsilon(t)$, a material model [11] is used (developed previously to characterize viscoelastic material). Previous research shows a pressure higher than 32 mmHg can cause pressure ulcer but it does not provide the time when subject will reach that value. Also other studies suggest 32 mmHg pressure is not the only threshold for ulceration. The pressure value can vary from subject to subject as per physical parameters (Body mass index). Therefore, by using this model (equation 3 and equation 4), it is possible to predict the risk for different individuals. Another reason to developing such model is, currently there is no prediction system available which predict the risk of ulceration in the human body based on subjects physical information and surface material's property at the same time. The conversion of PU factors are given in next section.

TABLE V: Conversion of age into risk scores

Age	Risk scores
<21	0
21-40	1
41-60	2
61-80	3
>81	4

C. Conversion of physiological parameters into risk values

1) age: In order to achieve the risk of pressure ulcer, the age of a subject is converted into risk score. This is done based on age vs. pressure ulcer formation risk [25]. Also the three risk assessment scales are used to identify how age is contributing towards formation of stage-1 PU. Once the relationship is established then the age values are converted into risk scores. Also, it has been shown that elderly subjects are more likely to form PU due to their skin type and tissue health [25]. Therefore, the score is high for 61-80 years and higher for >81 years. Conversion of age into risk is shown in Table VI.

2) BMI: The body mass index has a major role for PU formation [26]. People with BMI below (<20 kg/m^2) in average are considered as malnourished and these people are prone to develop PU. Also people with BMI indicating obeseness (>30 kg/m^2) are likely to develop PU. Research shows that people with average (20.1-24.9 kg/m^2) and above average (25.0-29.9 kg/m^2) BMI are less likely to develop PU compare to other two groups [26], [27]. A malnourished subject has higher chance to develop ulcer in bony prominence (heel and sacrum) because there is not enough soft tissue to support that area [28]. If the bony area is under continuous loading and the subject is immobile then blood flow in that area will decrease significantly. As a result stage-1 ulcer will develop. For an obese subject the scenario is different. An immobile obese people develop stage-1 PU under continuous external loading. Due to no movement, soft tissues do not get enough oxygenation and as a result it causes cell death and gradually leads to form stage-1 pressure ulcer. Obese subjects are likely to develop ulcer in the buttock area [28]. By studying the experimental results from previous research [29], the relationship of PU formation with body mass index is developed and then each group is converted into risk scores (shown in Table VII).

3) Risk assessment parameters (a,b,c): a, b, c are used to decide the importance of risk parameters. Here, a+b+c=1 and a<1, b<1 and c<1.

TABLE VI: Conversion of BMI into risk scores

BMI type	Risk score
Average (20-24.9)	1
Above average (25.0-29.1)	2
Obese >30	3
Below average <20	4

TABLE VII: values for a,b,c

	Physiological Parameters	Risk values of physiological Parameters	value
a	age	0	0.10
		1	0.20
		2	0.25
		3	0.30
		4	0.33
b	BMI	1	0.10
		2	0.25
		3	0.30
		4	0.33
c	Water Low	Low risk	0.10
		At risk	0.20
		High risk	0.25
		Very high risk	0.34

E.g. for a 25 years of old subject with below average (<20 kg/m^2) BMI and low risk Water Low score,

a=0.2
b=0.6
c=0.2

here b is high priority as the subject has a below average (<20 kg/m^2) BMI. But for the 84 years old subject with an average BMI (20.1-24.9 kg/m^2) and very high Water Low score

$$a = 0.33$$
$$b = 0.33$$
$$c = 0.34$$

Values for a, b, c are set to the system. So based on the subject's physiological properties, the system will decide the values for a,b,c. These values are shown in Table VIII.

D. Graphic User Interface (GUI) development for risk prediction model

Next, a graphical user interface (GUI) is developed in MATLAB. The objective of developing such GUI is to visualize the PU risk along with interface pressure and surface deformation more interactively. Water Low scoring system is also incorporated with the GUI so that components of the risk types can be seen separately. Figure 7 shows the developed GUI for risk prediction model. In order to obtain the PU risk for any individual using the GUI, following steps need to be completed.

- Step 1: On the right hand side, the Waterlow scale is provided and user needs to complete the Waterlow score first. Once Waterlow is completed, the system will generate the score along with risk type (shown in figure 7).
- Step 2: The user needs to insert subject's physiological parameters (age, weight and height) and based on that subject's body mass index (BMI) will be calculated by the system.
- Step 3: Young's modulus of the viscoelastic support surface needs to be set.
- Step 4: Sensor contact area needs to be set
- Step 5: After completing step 1-4, a user needs to select the area to get the risk of PU. Then the graphs appear. The Top left graph is the deformation of viscoelastic material. Top right one is the interface pressure graph due to deformation of the material. Bottom left one is the pressure distribution image at the skin and material level and finally the bottom right graph is the percentage of PU formation risk.

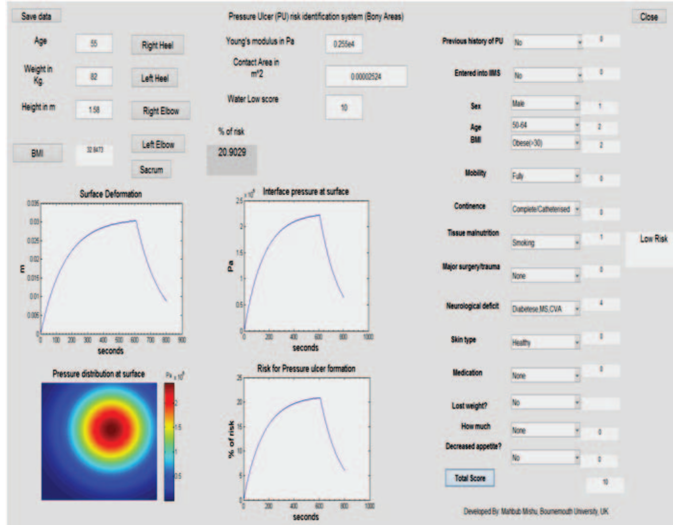

Fig. 7: Graphic user intertface (GUI) for PU risk prediction

V. Results

Here the results of PU risk for different individuals using the GUI are shown in this section. In order to generate the risk at different bony areas, four types of BMIs (below average, average, above average and obese) are considered along with different age groups. Theoretically, it has been established that people with obese BMI and below an average BMI (also known as malnutrant) are at more risk for ulceration compare to people with an average and above average BMI. Also elderly people are at more risk compared to younger age people due to skin and tissue conditions. Prediction of the PU risk formation percentage for different combination of physiological parameter is done by using the developed GUI. The results are given in figure 8 & 9 respectively. Here the percentage of risk at the right heel and the sacrum area are shown. The results shown in figure 8 and 9 matches closely with the theoretical results (people with below average BMI and obese BMI are at more risk compared to average and above average BMI). The % of PU risk at bony areas (heel, elbow and sacrum) are given in Table IX. The interface pressure (IP) values at the support surface are given in table X. Table IX and X shows the results of PU risk at different

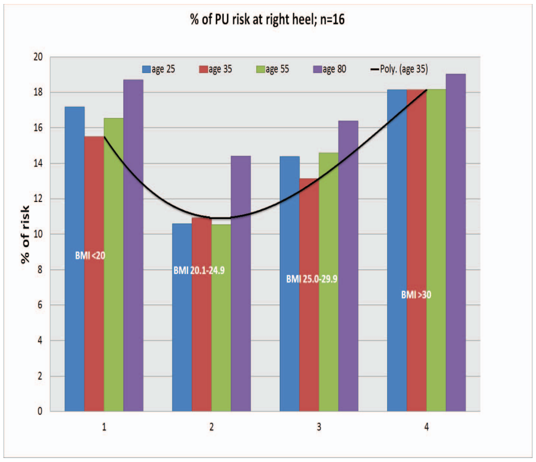

Fig. 8: % of PU risk at the right heel after 600 seconds (using GUI), n is the number of different combination of physiological parameters

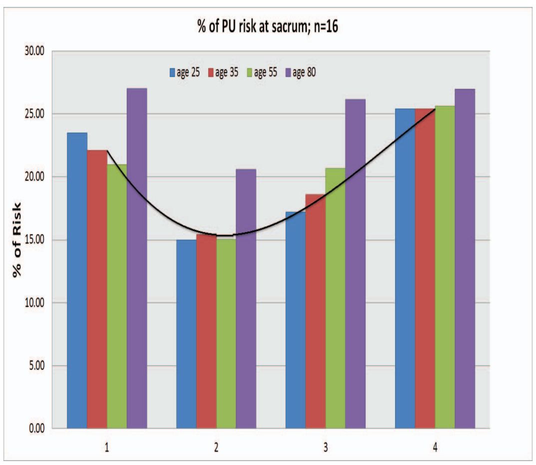

Fig. 9: % of PU risk at the sacrum after 600 seconds (using GUI),n is the number of different combination of physiological parameters

TABLE VIII: % of PU formation risk at different bony areas after 600 seconds, n=16

Age	BMI	% of Risk at right heel	% of risk at left heel	% of risk at right elbow	% of risk at left elbow	% of risk at sacrum
25	17.18	17.17	17.82	7.84	7.71	23.50
	24.81	10.6	11.00	4.91	4.80	15.00
	26.93	14.38	14.86	6.73	6.59	17.19
	30.86	18.14	18.71	8.55	8.37	25.38
35	18.52	15.5	16.15	7.01	6.86	22.12
	24.06	10.93	11.30	5.08	4.97	15.40
	27.69	13.14	13.63	6.10	5.95	18.57
	34.17	18.15	18.71	8.55	8.37	25.38
55	18.21	16.53	15.26	6.45	6.30	20.99
	21.26	10.54	11.00	4.77	4.67	15.05
	27.23	14.59	14.14	6.72	6.58	20.65
	30.36	18.17	18.80	8.44	8.26	25.61
80	19	18.7	19.06	8.32	8.13	27.00
	21.3	14.4	13.03	6.48	6.34	20.60
	26.3	16.39	15.12	8.40	8.22	26.12
	30.06	19.02	19.76	8.74	8.54	26.97

TABLE IX: Interface Pressure (IP) at support surface

Age	BMI	IP right heel in MPa	IP left heel in MPa	IP right elbow in MPa	IP left elbow in MPa	IP sacrum in MPa
25	17.18	1.34	1.43	0.81	0.66	1.75
	24.81	1.87	1.97	1.18	0.96	2.39
	26.93	2.05	2.14	1.39	1.06	2.60
	30.86	2.16	2.26	1.40	1.13	2.74
35	18.52	1.58	1.67	0.95	0.79	2.04
	24.06	1.93	2.03	1.25	1.00	2.46
	27.69	1.87	1.97	1.18	0.96	2.39
	34.17	2.16	2.26	1.39	1.13	2.74
55	18.21	1.34	1.43	0.82	0.66	1.75
	21.26	1.58	1.67	0.97	0.79	2.04
	27.23	1.81	1.91	1.14	0.93	2.32
	30.36	1.93	2.03	1.22	0.99	2.46
80	19	1.37	1.46	0.83	0.67	1.79
	21.3	1.52	1.61	0.94	0.75	1.97
	26.3	1.69	1.79	1.06	0.85	2.18
	30.06	1.75	1.85	1.10	0.88	2.25

locations in the human body. In Table IX, the percentage of risk is shown and the risk values show that people with below average and obese BMI have a higher risk compared to people with average and above average BMI. Also PU risk is higher for at 80 years old compared to 25 years old. Interface pressure (IP) is a result of skin and contact area on the surface. Table X shows the IP in different areas. The relationship between external load at one point with the total body weight is identified from the experiments. These relationships are used to characterize different bony locations of the human body. Based on these relationships, the prediction model can predict the surface deformation and the IP. Figure 10 shows the change in interface pressure due to different BMIs.

VI. Conclusion

The development of the risk predicting system for PU is done by considering a subject's physiological parameters and support surface property. The mathematical model is developed by converting physiological parameters into risk values. Also, the Water Low scale is incorporated in the GUI. This type of model will enhance the scope of pressure ulcer prevention research in the future. The developed model can be considered as a simulation toolbox where inputs are the subject's age, weight and height along with material information. The GUI will show PU risk at bony areas. The external load at different bony areas are identified by measuring for 11 different subjects. Experiments are conducted with subjects to identify parameters of risk. Conducting experiments using subjects to identify pressure ulcer formation could is a challenging task. Sometimes it takes

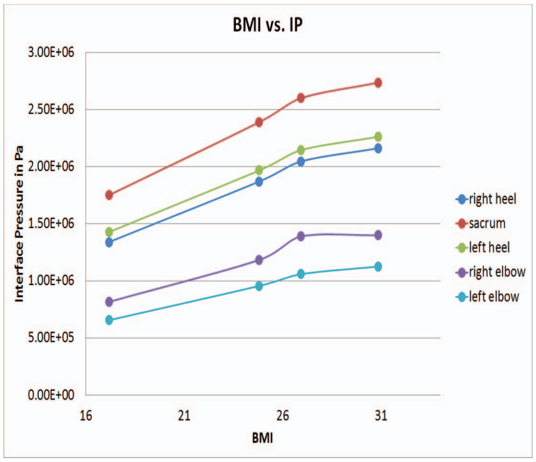

Fig. 10: Interface pressure due to different BMI

long time and it is also difficult to manage subjects for studies. Therefore, a toolbox is developed in MATLAB which can be used for a risk prediction system of pressure ulcer. Current model allows user to observe the interface pressure and surface deformation due to external load. Body support surface has a significant role in pressure ulcer formation in human body. The model allows a user to set the material property (Young's modulus) along with a subject's physiological parameters. Previous research in this field used measurement of perfusion, interface pressure and other parameters but the research did not include subject's physiological parameters with surface properties to predict risk of PU formation as it was presented in our model.

REFERENCES

[1] A. Manohar and D. Bhatia, "Pressure detection and wireless interface for patient bed," in *Biomedical Circuits and Systems Conference, 2008. BioCAS 2008. IEEE*. IEEE, 2008, pp. 389–392.

[2] L. R. Solis, A. Liggins, R. R. Uwiera, N. Poppe, E. Pehowich, P. Seres, R. B. Thompson, and V. K. Mushahwar, "Distribution of internal pressure around bony prominences: implications to deep tissue injury and effectiveness of intermittent electrical stimulation," *Annals of biomedical engineering*, vol. 40, no. 8, pp. 1740–1759, 2012.

[3] N. Graves, F. Birrell, and M. Whitby, "Effect of pressure ulcers on length of hospital stay," *Infection Control and Hospital Epidemiology*, vol. 26, no. 3, pp. 293–297, 2005.

[4] G. Bennett, C. Dealey, and J. Posnett, "The cost of pressure ulcers in the uk," *Age and Ageing*, vol. 33, no. 3, pp. 230–235, 2004. [Online]. Available: http://ageing.oxfordjournals.org/content/33/3/230.abstract

[5] C. Hsia, K. Liou, A. Aung, V. Foo, W. Huang, and J. Biswas, "Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system," in *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*. IEEE, 2009, pp. 6131–6134.

[6] M. Reddy, S. S. Gill, and P. A. Rochon, "Preventing pressure ulcers: a systematic review," *Jama*, vol. 296, no. 8, pp. 974–984, 2006.

[7] H. F. Clarke, C. Bradley, S. Whytock, S. Handfield, R. van der Wal, and S. Gundry, "Pressure ulcers: implementation of evidence-based nursing practice." *Journal of advanced nursing*, vol. 49, no. 6, pp. 578–590, 2005.

[8] C. V. Bouten, C. W. Oomens, F. P. Baaijens, and D. L. Bader, "The etiology of pressure ulcers: skin deep or muscle bound?" *Archives of physical medicine and rehabilitation*, vol. 84, no. 4, pp. 616–619, 2003.

[9] S. Saha, M. B. Smith, A. Totten, R. Fu, N. Wasson, B. Rahman, M. Motuapuaka, D. H. Hickam *et al.*, "Pressure ulcer treatment strategies: Comparative effectiveness," 2013.

[10] C. W. Oomens, D. L. Bader, S. Loerakker, and F. Baaijens, "Pressure induced deep tissue injury explained," *Annals of Biomedical Engineering*, pp. 1–9, 2014.

[11] M. C. Mishu, V. N. Dubey, T. F. Hickish, and J. Cole, "Mathematical modelling of different types of body support surface for pressure ulcer prevention," *International Journal of Medical, Pharmaceutical Science and Engineering*, vol. 8, no. 5, pp. 209–214, 2014.

[12] J. Waterlow, "Pressure sores: a risk assessment card." *Nursing times*, vol. 81, no. 48, pp. 49–55, 1984.

[13] P. Papanikolaou, P. Lyne, and D. Anthony, "Risk assessment scales for pressure ulcers: a methodological review," *International journal of nursing studies*, vol. 44, no. 2, pp. 285–296, 2007.

[14] L. Bolton, "Which pressure ulcer risk assessment scales are valid for use in the clinical setting?" *Journal of Wound Ostomy & Continence Nursing*, vol. 34, no. 4, pp. 368–381, 2007.

[15] C. L. Sistrom and C. W. Garvan, "Proportions, odds, and risk 1," *Radiology*, vol. 230, no. 1, pp. 12–19, 2004.

[16] D. M. Brienza, P. E. Karg, M. J. Geyer, S. Kelsey, and E. Trefler, "The relationship between pressure ulcer incidence and buttock-seat cushion interface pressure in at-risk elderly wheelchair users," *Archives of physical medicine and rehabilitation*, vol. 82, no. 4, pp. 529–533, 2001.

[17] E. Smejkal, M. Wissestad, M. Wood, and T. Kernozek, "The relationship between peak seat interface pressures and the braden scale."

[18] J. Kottner, A. Gefen, and N. Lahmann, "Weight and pressure ulcer occurrence: a secondary data analysis," *International journal of nursing studies*, vol. 48, no. 11, pp. 1339–1348, 2011.

[19] H. Goede, S. Tijssen, H. Schipper, N. Warren, R. Oppl, F. Kalberlah, and J. Van Hemmen, "Classification of dermal exposure modifiers and assignment of values for a risk assessment toolkit," *Annals of Occupational Hygiene*, vol. 47, no. 8, pp. 609–618, 2003.

[20] M. R. Spitz, W. K. Hong, C. I. Amos, X. Wu, M. B. Schabath, Q. Dong, S. Shete, and C. J. Etzel, "A risk model for prediction of lung cancer," *Journal of the National Cancer Institute*, vol. 99, no. 9, pp. 715–726, 2007.

[21] M. J. Magee, M. A. Herbert, T. M. Dewey, J. R. Edgerton, W. H. Ryan, S. Prince, and M. J. Mack, "Atrial fibrillation after coronary artery bypass grafting surgery: development of a predictive risk algorithm," *The Annals of thoracic surgery*, vol. 83, no. 5, pp. 1707–1712, 2007.

[22] E. V. McCloskey, H. Johansson, A. Oden, and J. A. Kanis, "From relative risk to absolute fracture risk calculation: the frax algorithm," *Current osteoporosis reports*, vol. 7, no. 3, pp. 77–83, 2009.

[23] D. Rocke, W. Murray, C. Rout, and E. Gouws, "Relative risk analysis of factors associated with difficult intubation in obstetric anesthesia," *Anesthesiology*, vol. 77, no. 1, pp. 67–73, 1992.

[24] G. Assmann, P. Cullen, and H. Schulte, "Simple scoring scheme for calculating the risk of acute coronary events based on the 10-year follow-up of the prospective cardiovascular münster (procam) study," *Circulation*, vol. 105, no. 3, pp. 310–315, 2002.

[25] C. Chai and D. Bader, "The physiological response of skin tissues to alternating support pressures in able-bodied subjects," *Journal of the mechanical behavior of biomedical materials*, vol. 28, pp. 427–435, 2013.

[26] C. VanGilder, G. MacFarlane, S. Meyer, and C. Lachenbruch, "Body mass index, weight, and pressure ulcer prevalence: An analysis of the 2006–2007 international pressure ulcer prevalence surveys," *Journal of nursing care quality*, vol. 24, no. 2, pp. 127–135, 2009.

[27] M. D. Stinson, A. Porter-Armstrong, and P. Eakin, "Seat-interface pressure: A pilot study of the relationship to gender, body mass index, and seating position," *Archives of physical medicine and rehabilitation*, vol. 84, no. 3, pp. 405–409, 2003.

[28] R. Sopher, J. Nixon, C. Gorecki, and A. Gefen, "Exposure to internal muscle tissue loads under the ischial tuberosities during sitting is elevated at abnormally high or low body mass indices," *Journal of biomechanics*, vol. 43, no. 2, pp. 280–286, 2010.

[29] D. R. Berlowitz, G. H. Brandeis, J. N. Morris, A. S. Ash, J. J. Anderson, B. Kader, and M. A. Moskowitz, "Deriving a risk-adjustment model for pressure ulcer development using the minimum data set," *Journal of the American Geriatrics Society*, vol. 49, no. 7, pp. 866–871, 2001.