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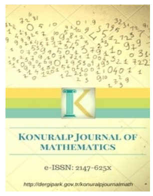

Analysis of Pressure Ulcer Formation Risk of In Different Regions of Human Body

Fadime Öğülmüş Demircan[1*], Metin Toz[2] and İbrahim Yücedağ[3]

[1]*Department of Computer Engineering, Faculty of Technology, Düzce University, Düzce, Turkey*
[2]*Department of Computer Engineering, Faculty of Technology, Düzce University, Düzce, Turkey*
[3]*Department of Computer Engineering, Faculty of Technology, Düzce University, Düzce, Turkey*
[*]*Corresponding author E-mail: fadimedemircan@duzce.edu.tr*

Abstract

Pressure ulcer is defined as the injuries resulted in the areas that are exposed to pressure for a long time in bedridden patients. It is a major problem that threatens these kinds of patients. The major risk factors cause pressure ulcer formations are pressure, temperature, humidity, and wetness.Pressure ulcers can occur in different body regions according to these factors. Therefore,the features of the body region that exposed to the risk factors are also important for pressure ulcer formation since the weight, sweating coefficient, and temperature values of the different parts of the human body vary. The human body can be evaluated in six regions as head, trunk, arm, hand, leg, and feet. In this study, the pressure ulcer formation risks for different body regions were calculated according to varying pressure, skin temperature, and humidity values by an improved formulation. And the pressure ulcer risks changes for the six regions of the body are evaluated.

Keywords: *Humidity ,Pressure, Pressure Ulcer, Risk of Pressure Ulcers, Temperature*
2010 Mathematics Subject Classification:

1. Introduction

The pressure ulcer is usually local tissue damage due to shearing with pressure or only pressure on the bone protrusions [1]. The most important reason for the formation of pressure ulcer is that the patients stay in the same position for a long time. For this reason, it is common in patients who have been depended on bed for a long time in [2] and [3]. In addition, factors such as urinary incontinence, diabetes, and vascular diseases that delay the healing of wounds adversely affect the treatment process while accelerating pressure ulcer formation in [4]. The risk factors for pressure ulcer formation include internal factors, such as infection, nutrition, age, weight, and skin temperature; and external factors such as pressure, shear force, ambient temperature, and humidity [5].

Pressure ulcer can progress at different rates in each patient due to these factors. This makes personal treatment particularly important. The European Pressure Ulcer Advisory Panel (EPUAP) and the National Pressure Ulcer Advisory Panel (NPUAP) of the United States examine the pressure ulcer in four stages lined up from the beginning as reddening discoloration, partial loss of the dermis layer, loss of skin and subcutaneous tissue layers, and full thickness tissue loss [1]. Some indicators are used by nurses to evaluate pressure ulcer risk in the patients at the hospitals. These charts mainly can be named as Norton, Waterlow, Braden, Gosnell, and Oh scales in [6].

Many patients in hospitals, especially bedridden ones, are at risk of developing pressure ulcers. Besides, many of them are being treated for pressure ulcer. In that regard, it seems like pressure ulcer is causing physical capacity and cost problems in hospitals and nursing homes, as well as reducing the life quality of patients. It is observed that the cost of preventing pressure ulcer seems to be lower than the cost of treatment of the illness in [7]. In that sense, pressure ulcer preventing studies becomes even more important.

Since the human body has different values of sweating coefficient, skin temperature, and pressure for different regions, in this paper, the pressure ulcer risk is calculated using an improved formula for different body regions, head, trunk, arm, hand, leg, and feet.

In the second part, a general literature review is given. In the third section, the regional risk calculation is shown on the graphs and the data on the graphs are examined. The results of the evaluation of the examined graphics are presented in the last section.

2. Literature Review

External factors such as pressure, temperature, and humidity are commonly evaluated in studies to prevent pressure ulcers. Among them, the pressure was found to be the most effective factor in [8]. When the studies in the literature are examined, it is seen that mattresses made up

***Email addresses*:** **, fadimedemircan@duzce.edu.tr (Fadime Öğülmüş Demircan), metintoz@duzce.edu.tr (Metin Toz), yucedagi@gmail.com (İbrahim Yücedağ)**

of sensors or sensor arrays are used to measure the relevant factors. In this context, some of the studies carried out have used commercial mattresses. In some cases, special mattress designs were made for the researches because of the high costs of the commercial mattresses.
An intelligent bed receiving information from different sensors placed on the bed to measure values such as the patient's pressure map, humidity, temperature, blood pressure, and mobility has been proposed by [9] .
Pereira et al. developed an active monitoring system that warns the nurse when the measured humidity values exceed a certain threshold using a textile humidity sensor matrix in [10].
El-Fehri et al. proposed an algorithm for confirming the pressure distribution on a mattress that is divided into cells and composed of pressure sensors in [11].
Ostadabbas et al. first designed a new scheduling algorithm that targets patients to change their positions at calculated intervals in [12]. Then, the designed algorithm was developed and the average time between patient positions was calculated using CSP (Constrained Shortest Path) algorithm in [13] and [14]. Thus, it is aimed to reduce the total cost of nursing service by estimating the time of relocation of each patient and future position information.
In a study carried out by Farshbaf et al. using a commercial mattress, a software platform was proposed for monitoring pressure ulcer formation in [15]. The developed software calculates the risk of pressure ulcer formation for different body regions of the patient and determines the next position.
Gefen has developed a mathematical model for the prevention of pressure ulcer. In this model, critical time is calculated depending on the effects of pressure, temperature, and humidity in [16]. This critical time gives an idea of the estimated time for pressure ulcer formation.
The mathematical model proposed by Gefen [16] was developed with adding the wetness parameter by Demircan et al. [17]. The obtained simulated results show that the wetting parameter has an effect of accelerating the pressure ulcer formation.
In order to prevent pressure ulcers, Mishu et al. developed a new support surface model by adhering to the Maxwell model, the Kelvin-Voigt model, and the Maxwell Wiechert model, thereby reducing the ulcer formation according to the feature of the support surface in [18].
In studies conducted to prevent pressure ulcer, it is important to work on the human thermal model since the change of human body temperature, sweating rate, and evaporation of sweating are also important. These studies can be given as follows.
The rate of sweating, which is important for the calculation of pressure ulcer risk, has been calculated by Nadel et al. [19] and by Fiala et al. [20].
The realization of the sweating brings the sweat evaporation. Calculation for the sweating evaporation is done by using the formulas developed in several studies in [21], [22], [23] and [24].
In this section, we refer to studies in the literature to prevent pressure ulcers. These studies show that the number of studies on regional differences in the body is low. Because different body regions have different characteristics due to sweating, skin temperature, weight, etc., it seems that regional examination of pressure ulcer risk is important for preventive studies.

3. Mathematical Model

In this study, we aimed to determine the pressure ulcer risk in different regions of human body. Therefore, we derived a mathematical model by using the general pressure ulcer risk formulation of Gefen [16] given in the equation 3.1, the sweating rate formula given in [26] as in the equation 3.2 and proposal by Demircan et al. [25] about the rate of evaporation of perspiration given in Equation 3.3. In their proposal, Demircan et al. [25] calculated the rate of evaporation of perspiration for the different regions of human body and proposed to use these rate in the formula given by Gefen [16].

$$\frac{\Delta V(t)}{V} = \int_0^t \left(\dot{Sw} - \dot{Ev} - \dot{Dr}\right) dt' \tag{3.1}$$

$$SW = \gamma x \left\{W_s \Delta T_s + W_H \Delta T_H\right\} 2^{(T-T_0)/10} + PI \tag{3.2}$$

$$Ev = (he \times Fpcl \times (Ps - Pa) \times w \times Ad) \tag{3.3}$$

In (3.1), $\dot{Sw}$, $\dot{Ev}$ and $\dot{Dr}$ are the rate of production of perspiration, the rate of evaporation of perspiration and the rate of drainage of perspiration out of the body region via the covering, respectively. In (3.2), γx is the sweating coefficient for each body region given in [20], PI is the amount of water that is lost during sweating without awareness ($0.63g/min$), T_s is body temperature and T_H is hypothalamus temperature (core temperature). W_s and W_H are shown with the following equations.

$$W_s = \alpha_{11} \tanh\left(\beta_{11}(T_s - T_{s0}) - \beta_{10}\right) + \alpha_{10} \tag{3.4}$$

$$W_H = \alpha_{21} \tanh\left(\beta_{21}(T_H - T_{H0}) - \beta_{20}\right) + \alpha_{20} \tag{3.5}$$

As indicated in [27], T_{s0} and T_{H0} represent the initial temperatures at the thermo-neutral conditions.
The equation (3.2) defines the sweating rate for a human body [26]. On the other hand, in order to using this rate in the equation (3.1), we divided it by the maximum amount of sweating for a human body, $Sw_{\max} = 16.2(g/min)$, given in [24].

$$\dot{Sw} = \frac{\gamma x \left\{W_s \Delta T_s + W_H \Delta T_H\right\} 2^{(T-T_0)/10} + PI}{Sw_{\max}} \tag{3.6}$$

In the equation (3.3),he is the evaporative heat transfer coefficient, $he = k \times hc$ ($k = 2.2K/Torr$), ($Torr$ is a pressure unit equal to $mmHg$)and hc is heat transfer coefficient, Pa is the water vapor pressure at the ambient temperature, Ps is the water vapor pressure at the body temperature, Ad is the body area, w is the wetness [24] and $Fpcl$ is permeation efficiency factor of clothing. In the same manner by the sweating rate formula, the equation (3.3) should also be divided by the maximum amount of evaporation of the perspiration, $Ev_{\max} = (he \times Fpcl \times (Ps - Pa) \times Ad)$ as given in the equation (3.7) [27].

$$\dot{E}v = \frac{he \times Fpcl \times (Ps - Pa) \times w \times Ad}{Ev_{\max}} \tag{3.7}$$

By replacing the equations (3.6) and (3.7) in the equation (3.1), the formula to calculate pressure ulcer risk according to the different regions of the human body can be defined as following [16];

$$t^c = \left\{ \frac{\theta_{s0} - 0.4P}{(0.5P + 0.8\theta_{s0})\left\{ \frac{\gamma x \left\{ Ws\Delta Ts + W_H \Delta T_H \right\} 2^{(T-T_0)/10} + PI}{Sw_{\max}} - w(1-RH) - \dot{D}r \right\}} \right. \tag{3.8}$$

In the equation (3.8), P is the pressure influenced to the body region, RH is the relative humidity, and $\dot{D}r$ is a constant number used instead of the rate of drainage of perspiration out of the clothing, and t^c is the critical time point for occurring of the pressure ulcer in a body region. The time for occurring of the pressure ulcer is calculated as dimensionless time with the model obtained in equation (3.8). When the time value is low, the result is that the pressure ulcer risk is high.

4. Experimental Results

In studies to prevent pressure ulcers, the human body has been evaluated as a whole. In our study, pressure ulcer risk was examined for six regions of body head, trunk, arm, hand, leg, and feet for varying body temperature, pressure, and relative humidity values. In order to calculate the pressure ulcer risk for different body regions. The features of these regions should be given. Therefore, we used the regional sweating coefficients, regional body first temperature, core temperature, and field data given in [28]. These values are summarized in *Table 1*.

Table 1 Sweating coefficient, Skin Temperature, Core Temperature, Area values according to body regions [28].

	Area(m^2)	Sweating coefficient	Skin Temp.	Core Temp.
Head	0.1326	0.081	34.58	36.96
Trunk	0.6804	0.481	33.62	36.89
Arms	0.2536	0.154	33.25	35.53
Hands	0.0946	0.031	35.22	35.41
Legs	0.5966	0.218	34.10	35.81
Feet	0.1299	0.035	35.04	35.14

Using the formula given in the equation (3.4) and coefficients in the *Table 1* pressure ulcer risk for the different body regions can be calculated. In this section we presented three experiments based on these formula and coefficients as follows;

Experiment 1: In the first experiment it was assumed that the pressure value to be $5kPa$, the body temperature as between $35^o\ C$ and $40^o\ C$, and relative humidity as 50%. According to these values the graphs in *Figures 4.1.a* and *4.1.b* were obtained.

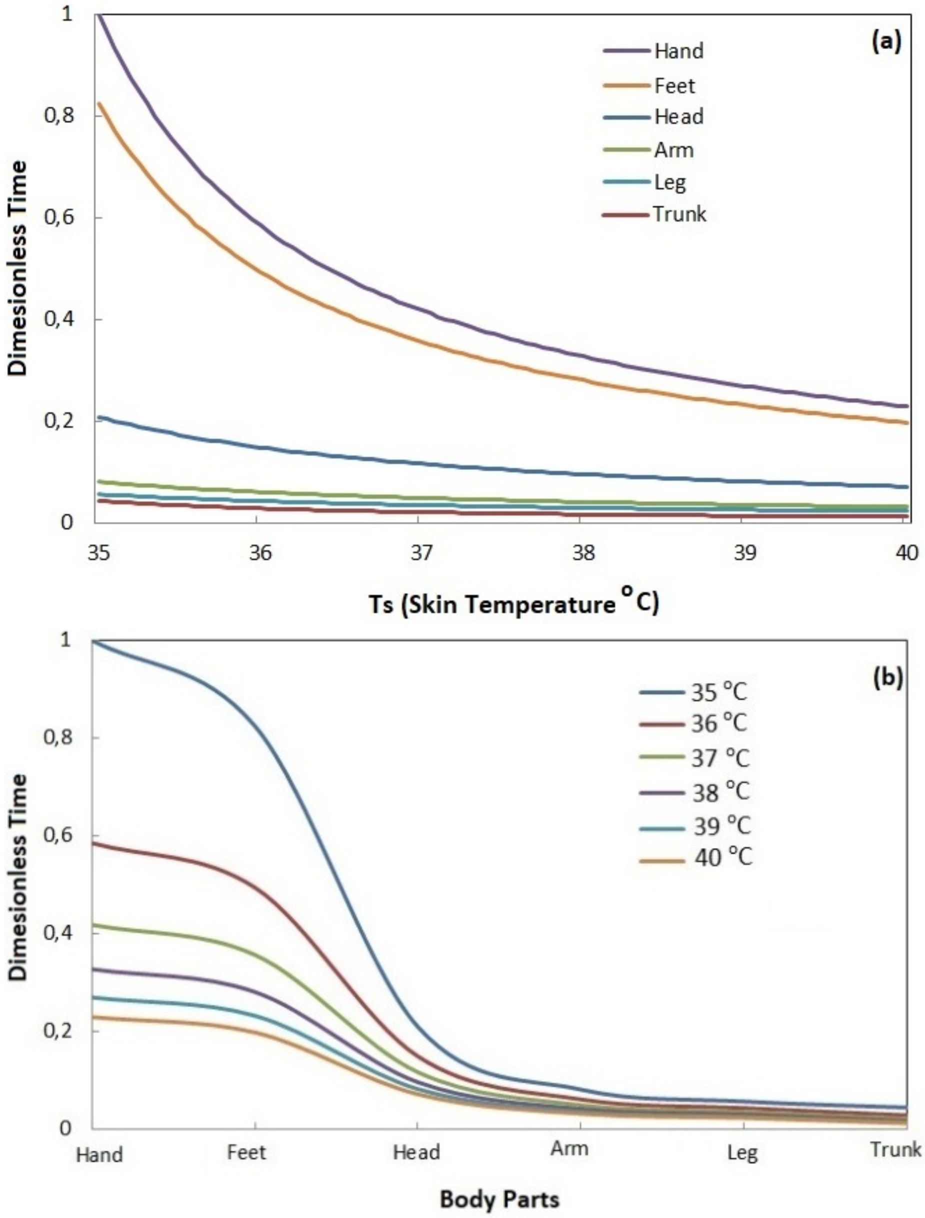

Figure 4.1: Risk of pressure ulcer occurring on the different body regions when body temperature varies between 35^o C and 40^o C **a)** The change of the risk according to the body temperature, **b)** The change of the risk according to the different body regions.

In the *Figure 4.1.a* the change in the risk of pressure ulcer formation at six regions according to increasing body temperature is shown, while *Figure 4.1.b* shows the risk formation according to the body regions between 35^o C and 40^o C. According to the *Figure 4.1.a*, as the skin temperature increases the time for pressure ulcer formation is shortened and therefore, the risk is increased (the risk value changed from 1 to 0.02) when the relative humidity is 50% and the applied pressure is $5kPa$.

Thus, it can be said that the higher the body temperature, the shorter the time for pressure ulcer formation. In *Figure 4.1.a*, also it is seen that the risk for body regions is increased with the order of hand, feet, head, arm, leg, and trunk. According to this order and the coefficients given in the *Table 1*, it is seen that the sweat coefficient is higher in the trunk where the risk formation is also excessive. In addition to the sweating coefficient, it is also observed that the weight of the relevant body region, and the change in skin temperature given in *Table 1* change the pressure ulcer risk. And also, it can be said that the lower weight of the hand and feet areas decrease the risk, while the risk in the head, arm, leg, and trunk regions is proportional to the sweating coefficient.

In *Figure 4.1.b*, the regional variation of the risk formation appears more clearly. It is presented there that the trunk area has a high risk and it increases as $35^oC \to 0.044$, $36^oC \to 0.028$, $37^oC \to 0.021$, $38^oC \to 0.017$, $39^oC \to 0.014$ and $40^oC \to 0.012$

Experiment 2: The second experiment was conducted to see effect of the influenced pressure. In this experiment the body temperature is assumed to be 35^oC, the pressure value is accepted as varying between 5 kPa and 60 kPa, and the relative humidity is defined as 50%. According to these values the graph of *Figure 4.2.a* is obtained.

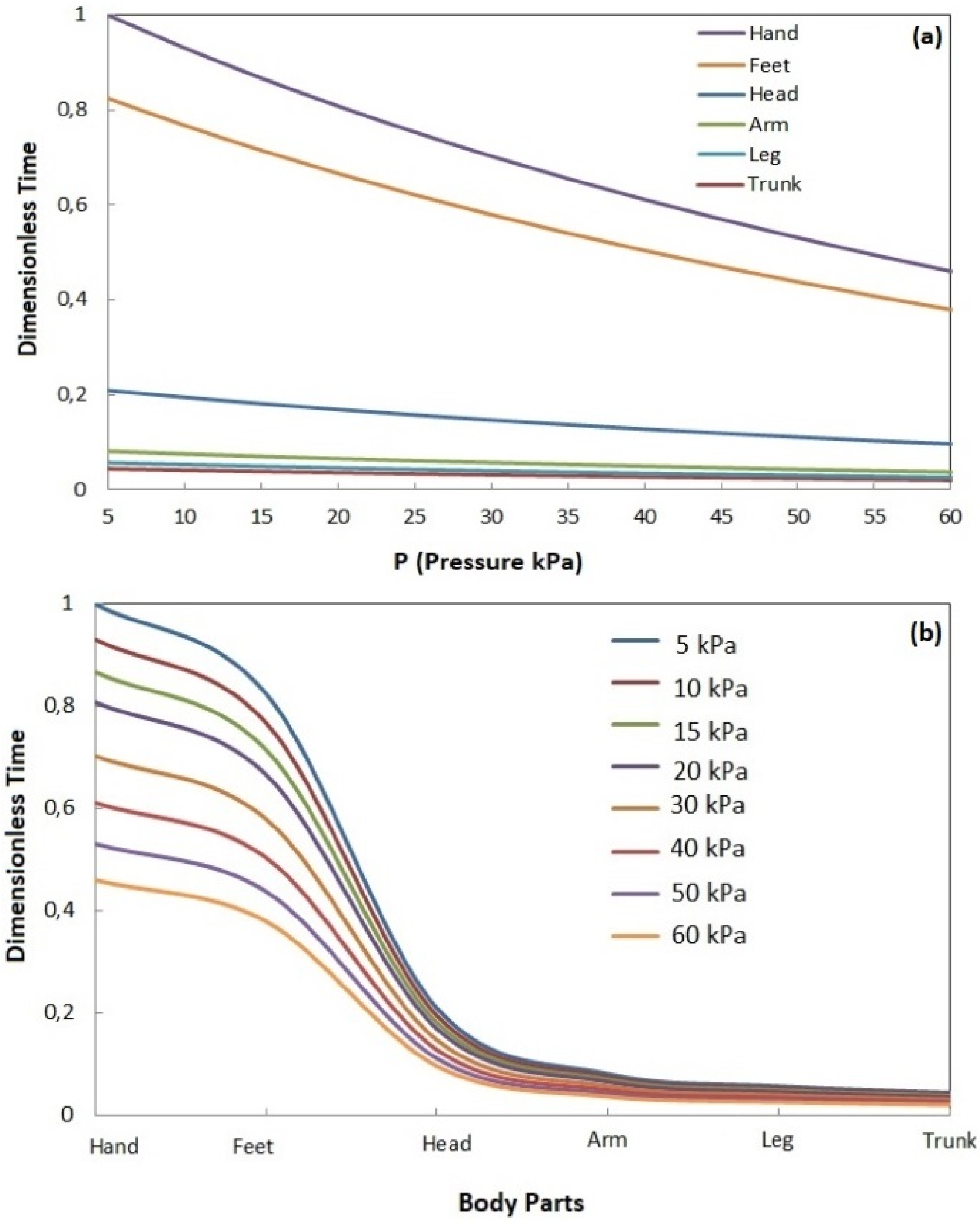

Figure 4.2: Pressure ulcer risk that occurs when the pressure value changes between 5 *kPa* and 60 *kPa* **a)** The change of the risk according to the pressure value, **b)** The change of the risk according to the different body regions.

In *Figures 4.2.a* and *4.2.b*, the risk value changed from 1 to 0.02. *Figure 4.2.b* shows the change in the risk of pressure ulcer formation in the 6 regions according to the increasing pressure value, whereas the risk formation in the pressure values between 5 *kPa* and 60 *kPa* in *Figure 4.2.b* is given according to the body regions. In *Figure 4.2.a*, the risk is increased with the hand, feet, head, arm, leg, and trunk order. In terms of the risk formation according to the different body regions, it is seen that the regional weight of the body, the sweating coefficient, and the change in the skin temperature values change the pressure ulcer risk.

In *Figure 4.2.b*, the regional variation of risk formation is clearer. It is observed that the trunk area is riskier, and the pressure increases the risk as in 5 $kPa \rightarrow 0.044$, 10 $kPa \rightarrow 0.041$, 15 $kPa \rightarrow 0.038$, 20 $kPa \rightarrow 0.035$, 30 $kPa \rightarrow 0.031$, 40 $kPa \rightarrow 0.027$, 50 $kPa \rightarrow 0.023$ and 60 $kPa \rightarrow 0.020$.

Experiment 3: The last experiment was performed to see the pressure ulcer risk formation according to the relative humidity. In this experiment, the body temperature and the influenced pressure are accepted as 35^oC and as 5 *kPa*, respectively. And, the relative humidity is changing between $0-100\%$ and the graph in *Figure 4.3.a* is obtained.

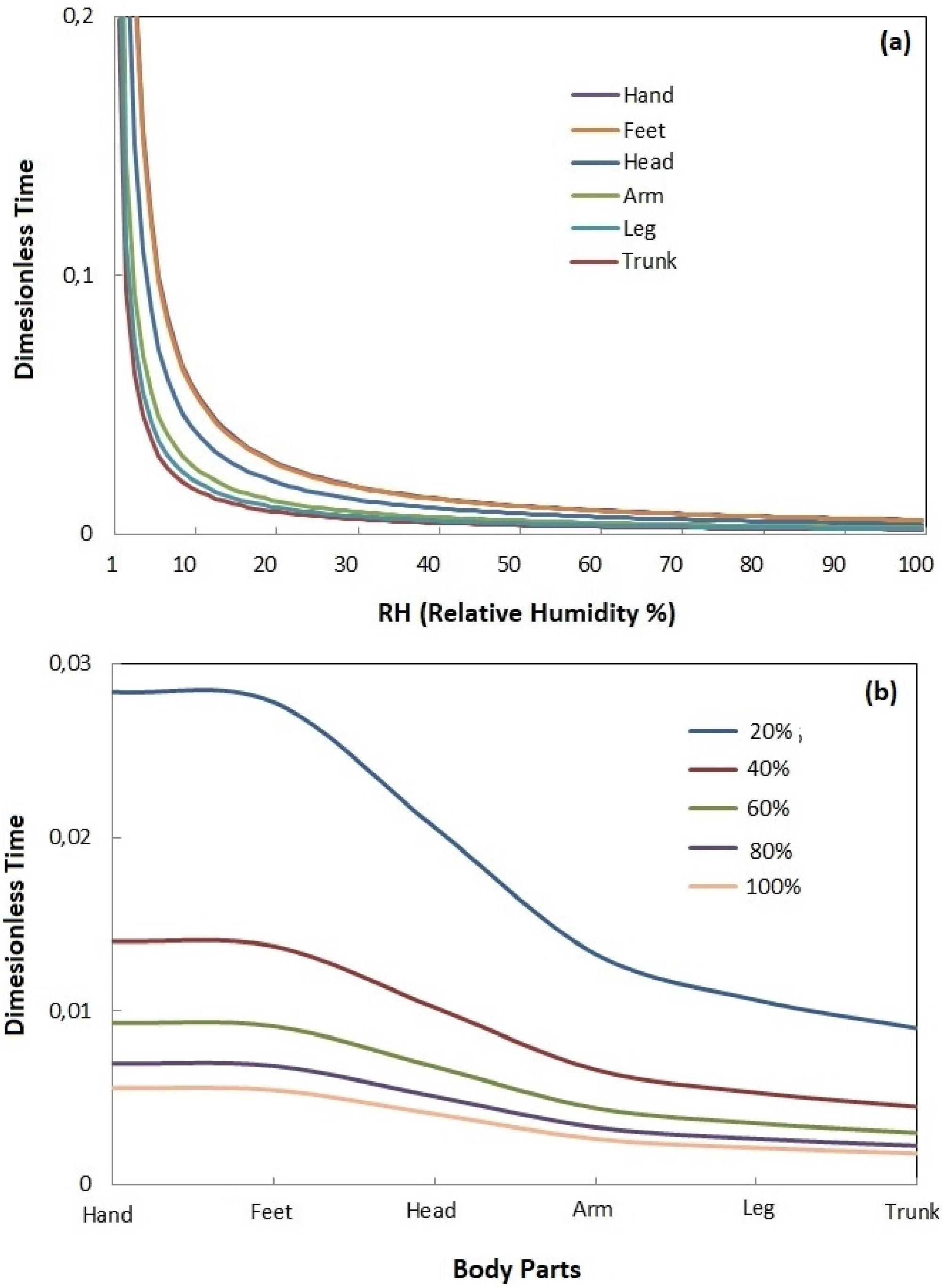

Figure 4.3: Pressure ulcer risk when relative humidity varies between 1% and 100% **a)** The change of the risk according to the relative humidity, **b)** The change of the risk according to the different body regions.

Figure 4.3.a shows the change in the risk of pressure ulcer formation in 6 regions according to the increasing relative humidity value. Meanwhile, *Figure 4.3.b* shows the risk formation between 20% and 100% relative humidity values according to body regions. In *Figure 4.3.a*, it can be seen that the risk is increased as hand, feet, head, arm, leg, and trunk. It is observed that the trunk area is riskier and the risk is increased as $0.0090, 0.0044, 0.0029, 0.0022$, and 0.0017 with the increase of relative humidity as $20\%, 40\%, 60\%, 80\%$, and 100% respectively.It is also observed that the risk value is higher in the trunk area due to weight and sweating coefficient. When we look at the graphs for body temperature in *Figure 4.1*, for the pressure in *Figure 4.2*, and for relative humidity in *Figure 4.3*, it is clear that the increase in the relative humidity further increases the pressure ulcer risk comparing to the changes in pressure and body temperature.

5. Conclusion

Pressure ulcer is a major problem in the world due to the facts that it is very common in bedridden patients, and the treatment has a high cost. Preventive work is important for this purpose. In that regard, an improved mathematical model was developed to calculate pressure ulcer risk. When studies in the literature were examined, pressure, temperature, humidity, and wetness parameters were used among the external factors that have high effects on the formation of pressure ulcer. The human body's regional characteristics such as weight, sweating rate, and temperature show difference. In our study, the effects of these differences on the pressure ulcer formation were examined for six regions of the body: head, trunk, arm, hand, leg, and feet for varying body temperature, pressure, and relative humidity. As a result, the effects of

regional differences in the pressure ulcer formation are shown graphically. Here, the pressure ulcer risk is increased with the changes of the regional sweating coefficient, body temperature, and weight. In addition, it is also observed that the increase in relative humidity has increased the risk even more.
This study showed that the regional examination of the pressure ulcer risk of the patients showed better results in preventing pressure ulcer. Thus, it is aimed to reduce the workload of nurses in preventing pressure ulcer, as well as to shorten the length of time patients spend in the hospital.

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References

[1] NPUAP, "National Pressure Ulcer Advisory Panel", http://www.npuap.org/,2017.
[2] Reenalda, J., Dynamic sitting to prevent pressure ulcers in spinal cord injured. University of Twente, 2009.
[3] Shahin, E. S.,Dassen, T., &Halfens, R. J., Pressure ulcer prevalence and incidence in intensive care patients: a literature review. Nursing in critical care, Vol:13, No.2 (2008), 71-79.
[4] Smith, M. B.,Totten, A., Hickam, D. H., Fu, R., Wasson, N.,Rahman, B., and Saha, S., Pressure Ulcer Treatment Strategies A Systematic Comparative Effectiveness Review. Annals of internal medicine,Vol:159, No.1 (2013), 39-50.
[5] Coleman, S., Gorecki, C., Nelson, E. A., Closs, S. J., Defloor, T., Halfens, R., and Nixon, J., Patient risk factors for pressure ulcer development: systematic review. International journal of nursing studies, Vol:50, No.7 (2013),974-1003.
[6] Matsushita, H., Innovation in health services: technology transfer and diffusion of risk assessment tools for the treatment of pressure ulcer. In Technology Management in the Energy Smart World (PICMET), 2011, Proceedings of PICMET'11: (pp. 1-9). IEEE.
[7] Demarré, L., Van Lancker, A., Van Hecke, A., Verhaeghe, S., Grypdonck, M., Lemey, J., and Beeckman, D., The cost of prevention and treatment of pressure ulcers: A systematic review. International journal of nursing studies, Vol:52, No.11 (2015, 1754-1774.
[8] Marchione, F. G.,Araújo, L. M. Q., &Araújo, L. V., Approaches that use soft ware to support the prevention of pressure ulcer: a systematic review. International journal of medical informatics, Vol:84, No.10 (2015), 725-736.
[9] Yousefi, R., Ostadabbas, S., Faezipour, M., Nourani, M., Ng, V.,Tamil, L., and Pompeo, M., A smart bed platform for monitoring & Ulcer prevention. In Biomedical Engineering and Informatics (BMEI), 2011 4th International Conference on (Vol. 3, pp. 1362-1366),(2011, October),IEEE.
[10] Pereira, T.,Silva, P., Carvalho, H., &Carvalho, M., Textile moisture sensor matrix for monitoring of disabled and bed-rest patients. In EUROCON-International Conference on Computer as a Tool (EUROCON), 2011 IEEE (pp. 1-4), (2011,April), IEEE.
[11] Elfehri, J., Boussu, F., Koncar, V., &Vasseur, C., Novel approach of ulcer prevention based on pressure distribution control algorithm. In Mechatronics and Automation (ICMA), 2011 International Conference on (pp. 265-270),(2011,August), IEEE.
[12] Ostadabbas, S., Yousefi, R., Faezipour, M., Nourani, M., &Pompeo, M., Pressure ulcer prevention: An efficient turning schedule for bed-bound patients. In Life Science Systems and Applications Workshop (LiSSA), 2011 IEEE/NIH (pp. 159-162), (2011, April), IEEE.
[13] Ostadabbas, S., Yousefi, R., Nourani, M., Faezipour, M., Tamil, L.,and Pompeo, M., A posture scheduling algorithm using constrained shortest path to prevent pressure ulcers. In Bioinformatics and Biomedicine (BIBM), 2011 IEEE International Conference on (pp. 327-332),(2011, November),IEEE.
[14] Ostadabbas, S., Yousefi, R., Nourani, M., Faezipour, M., Tamil, L., and Pompeo, M. Q., A resource-efficient planning for pressure ulcer prevention. Information Technology in Biomedicine, IEEE Transactions on, Vol:16, No.6,(2012), 1265-1273.
[15] Farshbaf, M., Ostadabbas, S., Yousefi, R., Nourani, M., &Pompeo, M., Pressure ulcer monitoring and intervention: A software platform. In Bioinformatics and Biomedicine Workshops (BIBMW), 2011 IEEE International Conference on (pp. 897-898),(2011, November), IEEE.
[16] Gefen, Amit., How do microclimate factors affect the risk for superficial pressure ulcers: a mathematical modeling study. Journal of tissue viability, Vol: 20, No.3,(2011),81-88.
[17] Demircan, F. Ö, Yücedağ, İ., Toz M., Çakıcı , S., &Gedik, S. Basınç ülserinin önlenmesinde kullanılmak amacıyla geliştirilen bir maematiksel model. İleri Teknoloji Bilimleri Dergisi,Vol: 5, No.1.(2016).
[18] Mishu, M. C., Dubey, V. N., Hickish, T. F., & Cole, J., 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(2014), 209-214.
[19] Nadel, E. R.,Mitchell, J. W., &Stolwijk, J. A. J.. Control of localand total sweating during exercise transients. International journal of biometeorology, Vol:15, No.2 (1971), 201-206.
[20] Fiala, D.,Lomas, K. J., &Stohrer, M., Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. International Journal of Biometeorology, Vol:45, No.3,(2001), 143-159.
[21] Johnson, A. T., Biomechanics and exercise physiology: quantitative modeling. CRC Press,2007.
[22] Candas, V.,Libert, J. P., &Vogt, J. J., Human skin wettedness and evaporative efficiency of sweating. Journal of Applied Physiology, Vol:46, No.3 (1979), 522-528.
[23] Djongyang, N., Tchinda, R., and Njomo, D., Thermal comfort: A review paper. Renewable and sustainable energy reviews, Vol:14. No.9 (2010), 2626-2640.
[24] Holopainen, R., A human thermal model for improved thermal comfort. VTT Technical Research Centre of Finland, 2012.
[25] Demircan F. Ö., Toz M., Çakıcı S.,Yücedag İ . Basınç Ülseri Oluşum Sürecinin Matematiksel Olarak Modellenmesi üzerine Bir Derleme Çalışması , ASYU AkıllıSistemlerde Yenilikler ve Uygulamalari Sempozyumu,.(2016), 239-244
[26] Hirata, A.; Nomura, T.; Laakso, I. Computational estimation of body temperature and sweating in the aged during passive heat exposure. //International Journal of Thermal Sciences, Vol:89, (2015), pp.154-163.
[27] Candas, V.;Libert, J. P.; Vogt, J. J. Human skin wettedness and evaporative efficiency of sweating.// Journal of Applied Physiology,Vol:46, No.3 (1979), pp. 522-528.
[28] J.A.J. Stolwijk, Mathematical Model of Physiological Temperature Regulation in Man, 1971. NASA Contractor Reports