

ORIGINAL RESEARCH

Interface pressure, pressure gradient with pressure ulcer development in Intensive Care Units

Supriadi¹, Tomoe Nishizawa², Moriyoshi Fukuda², Yuka Kon², Matsuo Junko³, Suriadi³, Okuwa Mayumi², Nakatani Toshio², Sugama Junko², Sanada Hiromi⁴

1. School of Nursing Muhammadiyah Pontianak, West Borneo, Indonesia. 2. Department of Clinical Nursing, Graduate School of Medical Science, Kanazawa University, Kodatsuno, Kanazawa, Japan. 3. Faculty Nursing, Osaka Medical College, Takatsuki, Osaka, Japan. 4. Department of Gerontological Nursing/Wound Care Management, Graduate School of medicine, The University of Tokyo, Tokyo, Japan.

Correspondence: Sugama Junko. Address: Department of Clinical Nursing, Graduate School of Medical Science, Kanazawa University, 5-11-80 Kodatsuno, Kanazawa 920-0942, Japan. Email: junkosgm@mhs.mp.kanazawa-u.ac.jp

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Abstract

The pressure gradient can predict skin breakdown when combined with high pressure. We investigate the relationships between Peak Interface Pressure (PIP) and peak pressure gradient (PPG) for predicting and understanding the causes of pressure ulcers. Design of this research was a prospective cohort design. Pressure ulcers were identified and classified using the National Pressure Ulcer Advisory Panel and European Pressure Ulcer Advisory Panel. Interface pressure was measured at the patient's sacrum three times once every three days until pressure ulcers develop. The assessment was measured after the 24-hours monitoring period had expired for a newly admitted patient to the intensive care unit (ICU). The locations of the pressure ulcers were found using trace sheets. The 87 patients were obtained from two hospitals. The incidence of pressure ulcers was 12.6%. The PIP was 66.2 mmHg and PPG was 12.1 mmHg for a pressure ulcer compared to without a pressure ulcer ($p < .01$). The cut-off value for PIP was 50.0 mmHg and PPG was 8.0mmHg/cm. The PIP > 50.0 mmHg and PPG > 8.0 mmHg/cm were risk pressure ulcers. The correlation between the PIP and PPG were high correlation ($r = 0.925$). The PIP and PPG may be a useful indicator for the development of pressure ulcers.

Key words

Interface pressure, Peak interface pressure, Pressure gradient, Peak pressure gradient, Pressure ulcer, Intensive care unit, Incidence pressure ulcer, Category of pressure ulcer

1 Introduction

The study was carried out in Indonesia where the incidence of pressure ulcers was 28.4% in intensive care units (ICUs)^[1]. Suriadi *et al.*^[2] found that the *incidence* of pressure ulcers was higher in Indonesia than in other Asian countries such as China 2.1%^[3], South Korea 10.5%^[4], and Japan 11.2%^[5] and other countries worldwide such as Germany 3.3%^[6], Spain 12.4%^[7], and the United States 16%^[8]. The high incidence of pressure ulcers in Indonesia should be a major concern for all healthcare providers that aim to prevent the formation of pressure ulcers and it is a priority for nursing research in Indonesia.

Prevention and reduction of the occurrence of pressure ulcers in Indonesian ICUs needs to be studied. Suriadi, Sanada H, Sugama J, Thigpen B, Subuh M (2008) ^[1] reported that the risk factors for pressure ulcer development were interface pressure (IP), temperature, and smoking. When a patient in the ICU receives a medication to decrease the body temperature, the body temperature may be febrile to normal. The patient may have had a smoking habit before entering the hospital. The IP may be related to pressure ulceration because the pressure ulcer develops from above toward the direction of the sacrum. The National Pressure Ulcers Advisory Panel (2007) ^[9] define IP is the force per unit area that acts perpendicularly between the body and the support surface. Suriadi *et al.* ^[2] in their study found that the IP was significant to predict the occurrence of pressure ulcers with a cut-off point more than 35 mmHg in supine position. One study reported the ICU patients sitting out of bed have a high seating IP; specifically, the PIP (Peak Interface Pressure) was 90-101 mmHg in patients who used a regular cushion ^[10]. Unfortunately, the study was not related to the occurrence of pressure ulcer development. Research by Suriadi *et al.* ^[2] confirms the findings that IP was an important risk factor that contributes to pressure ulcer development. Therefore, it can be postulated that a lower IP was likely to decrease the risk of pressure ulcer development.

The IP is not the only factor that contributes to the occurrence of pressure ulcers, but the Peak Pressure Gradient (PPG) also. Mueller MJ *et al.* ^[11] found that the PPG can predict skin breakdown of the plantar surface in patients with diabetes. The PPG is the highest pressure on the Pressure Gradient (PG) or in the direction of the pressure derivative at the allocation of the peak pressure on the surface of the body, and the PG is the pressure differential or the change in pressure over a distance and measured with a change in mmHg per cm² or inch ^[12]. The PPG measured in several studies was conducted in patients with diabetic neuropathy and assessed the PPG in patients that contributed to skin damage. A previous study showed that the PPG was 143% higher in the front of the foot than in the rear of the foot, even when compared with peak plantar pressure of the diabetic patient. The PPG must be a better indicator than the peak plantar pressure alone in distinguishing patients at risk for skin breakdown ^[11]. The study was not associated with the occurrence of pressure ulcer development.

Pressure on the surface of the body with the support surface is at risk factor for pressure ulcer development, but it is not merely pressure alone that causes a pressure ulcer; there is a possibility of other factors, namely the PG. Until now, there was no evidence of pressure ulcer development by the PG. There does not yet appear to be a specific threshold of PG that predicts skin breakdown. A study to investigate the relationship between PIP and PPG with pressure ulcers development was needed and the outcomes could be used to reduce the incidence of pressure ulcers in Indonesia. Essentially, the goal of this study is to determine the relationships between PIP and PPG for prediction of pressure ulcer development in ICUs patients.

2 Methods

2.1 Materials

The IP was recorded by a scanning aid device namely Palm Q; Cape Co. Ltd., Yokosuka, Japan (see Figure 1). The dimensions and weight were width 6.5 cm X length 7.5 cm X thick 3.5 cm and 160 gram. It has five sensors per square centimeter, each in a fan shapes, flexible sensors sized width 13 cm X length 13 cm, and a cable length of 75 cm. The accuracy of this instrument was 0 – 200 mmHg, and ± 3 mmHg, (at 0 – 40°C), respectively. The correlation coefficient of pressure evaluator scores for interrater test was 0.992 to 1.000 and 0.737 for intra rater test. Then the validity test of pressure evaluator was significant difference ($p < .001$) between patients with pressure ulcer and patients without pressure ulcer ^[13].

A prospective cohort design was conducted between March and October 2011. The research was conducted at two hospitals in Pontianak, Indonesia. Ten (10) of 446 beds in hospital A (Soedarso General Hospital) and 16 of 296 beds in hospital B (St. Antonius General Hospital) were allotted to the ICUs.



Figure 1. Palm-Q Device

The inclusion criteria were patients ≥ 18 years of age, first admission to the ICU, and immobilization. Patients had an expected length of stay of at least 2 days (48 hours) after initial data collection, and gave informed consent. All subjects were required to be free of pressure ulcers at the beginning of the study. The exclusion criteria were patients who could not be manipulated (difficult to identify the skin condition every day and bad conditions) and any patient who did not wish to participate in the study. A convenience sample was patients in ICUs. The sample size of the follow-up cohort was calculated so that the incidence of pressure ulcers could be measured with a relative precision of 40%, and a confidence level of 95% [14].

The measurements were on the pressure scanning aid on the area 4 cm below the sacrum in the supine position. The measurement was divided into three areas (central, right, and left areas) of the sacrum (see Figure 2). Interface pressure measurement and pressure gradients were taken at the patient's sacrum every three days and repeated three times during each assessment until pressure ulcers occurrence. The skin over the sacrum of all patients was observed every day until discharge from the ICU and a picture was taken every day with a digital camera. The study recorded the gender, age, medical diagnosis, type of mattress, body mass index, Braden score, Suriadi Sanada (SS) scale, length of stay, and APACHE II score. After a pressure ulcer developed, the occurrence, category, and location of the pressure ulcers were assessed every day. The category system was based on the National Pressure Ulcer Advisory Panel (NPUAP) and the European Pressure Ulcer Advisory Panel [15]. For patients who did not develop a pressure ulcer, the IP was used for the first assessment. For patients who did develop a pressure ulcer, the value obtained in the assessment before the pressure ulcer developed was used. After selecting the IP data, we calculated the PIP and PPG values that had the highest values for the IP and PG. According to research by Mueller MJ *et al.* [10] the PG values were calculated by subtracting the pressure in each node around the peak pressure from that in the adjacent node and dividing by the distance between the central portions of the sensor. The PG in this study was calculated as follows: PIP minus IP divided distance between by sensor to sensor. So PG is use mmHg/cm as unit.

$$\text{This formula is PG} = \frac{(\text{PIP} - \text{IP})}{\text{Distance}} \quad (1)$$

$$\text{The distance formula is: } c^2 = a^2 + b^2 \quad (2)$$

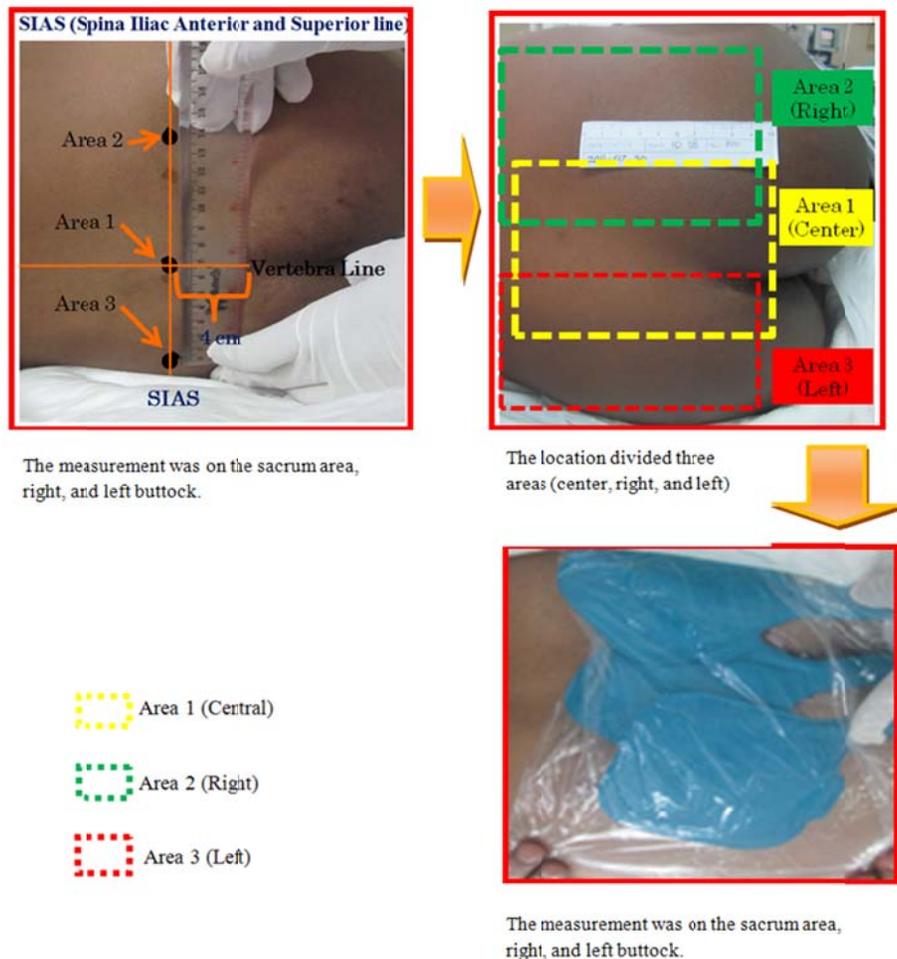


Figure 2. The measurement of pressure scanning aid for interface pressure

2.2 Data analysis

Demographic and clinical characteristics data were used as descriptive analysis. The means values and standard deviations (SD) of the PIP and PPG were used and a t-test was used to compare the means in patients with and without pressure ulcers. The diagnostic probability was used to calculate the range of the PIP, and a Receiver Operator Characteristic (ROC) curve was used to confirm the PIP cut-off and Area under Curve (AUC) values. When the cut-off value for a continuous diagnostic variable is increased (assuming that larger values indicate an increased chance of a positive outcome), the proportions of both true and false positives decreases. These proportions are the sensitivity and 1 – specificity, respectively. A graph of sensitivity against 1 – specificity is called a receiver operating characteristic (ROC) curve [16]. The Pearson correlation coefficient between PIP and PPG was used. All analyses were performed with the Statistical Product and Social Science software (version 15; SPSS, Inc., Chicago, IL, USA) and significance was set at a $p < .05$.

2.3 Ethical considerations

Before the study was conducted, the researchers obtained permission from the Ethics Committee of Kanazawa University (#302). The clinical research ethics committees in both hospitals approved the study protocol. Patients as subjects who wished to participate were then informed of their rights and the ability to drop out of the study at any time for their own reasons. Next, they obtained informed consent either by the patients themselves or family members. There were six nurses who helped complete this study by observing the patients' safety during investigation.

3 Results

3.1 Demographic data and clinical characteristics

A total of 108 patients were enrolled after meeting the initial study inclusion criteria. Of those, 21 patients were excluded because there were 18 patients because only one-time inspection and 3 patients within continence associated dermatitis and the remaining 87 patients participated in this study. The patients were male (47.54%), and female (52.46%) and mean age was 44.1 (SD ± 16.9) years. The mean length of stay in the ICU was 7.9 (SD ± 6.2) days, the mean APACHE II score was 11.5 (SD ± 4.9), SS scale was 3.49 (SD ± 2.5), Braden scale was 11.22 (SD ± 1.3), body mass index (BMI) was 25.5 (SD ± 5.0), then diagnoses for ICU admissions included head injury (39.1%), stroke (36.8%), post operation (16.1%) and others (8.0%) (see Table 1).

Table 1. Demographic and characteristics of patients (n = 87)

Subject	
Gender n (%)	
Male	40 (46.0%)
Female	47 (54.0%)
Age mean (SD)	44.1 (±16.9)
Length of stay mean (SD)	7.9 (±6.2)
APACHE mean (SD)	11.5 (±4.9)
SS scale mean (SD)	3.49 (±2.5)
Braden scale mean (SD)	11.22 (±1.3)
BMI mean (SD)	25.5 (±5.0)
Diagnoses n (%)	
Head injury	34 (39.1%)
Stroke	32 (36.8%)
Post Operation	14 (16.1%)
Others	8 (19.0%)
Mattresses n (%)	
Foam mattress	63(72.4%)
Air mattress	24 (27.6%)

3.2 PIP and PPG

The PIP mean was 66.2 and SD ± 42.0 mmHg for pressure ulcer development and the PIP mean was 42.7 and SD ± 14.8 mmHg with no pressure ulcer development, significant (*p*) was 0.000 and the PPG mean was 12.1 and SD ± 10.2 mmHg/cm with pressure ulcer development and the PPG mean was 6.6 and SD ± 3.6 mmHg/cm with no pressure ulcer development, significant (*p*) was .001 (see Table 2).

Table 2. The comparison of PIP and PPG of the pressure ulcer positive and pressure ulcer negative

	Pressure Ulcer (n = 11)	No Pressure Ulcer (n = 76)	<i>p</i> value
PIP (mmHg)			
mean ± SD	66.2 ± 42.0	42.7 ± 14.8	.000*
Range	35.0 – 160.0	14.5 – 89.5	
PPG (mmHg)			
mean ± SD	12.1 ± 10.2	6.6 ± 3.6	.001*
Range	5.0 – 37.9	1.3 – 16.0	

*Significance *p* < .05

3.3 Pressure ulcer development

The eleven (11) of 87 patients developed pressure ulcers. The pressure ulcer development of grade I was 45.5%, grade II was 36.4% and grade IV was 18.1%, respectively (see Table 3). The pressure ulcers were located on the right buttock for 4 patients, right and left buttocks in 3 patients, coccyx for 3 patients of central position and sacrum for 1 patient of central position (see Figure 3 a, b, c, and d).

Table 3. Category and incidence of pressure ulcer (n = 11)

Category or Grade of Pressure Ulcers	(n %)
I	5 (45.5)
II	4 (36.4)
III	0 (0.0)
IV	2 (18.1)
Pressure ulcers (n %)	
Pressure ulcer positive	11 (12.6%)
Pressure ulcer negative	76 (87.4%)



Figure 3. a) Pressure ulcers were located on the right buttock, b) Pressure ulcers were right and left buttock area, and c) Pressure ulcer on the coccyx of central area, and d) Pressure ulcer on the sacrum of central area.

3.4 ROC Curve PIP and PPG

The PIP has a cut-off score of 50.0 mmHg and was designated in the current study with a sensitivity of 45.5%, a specificity of 31.6%, a positive predictive value (PPV) of 29.2%, and a negative predictive value (NPV) of 83.3%, while the positive likelihood ratio was 2.2 with an overall accuracy of 59.8%. The ROC curves constructed an AUC of 0.668 with 95% CI, 0.490-0.826 (see Figure 4). The PPG has a cut-off value of 8.0 mmHg/cm and was designated in the current study with a sensitivity of 36.4%, a specificity of 22.4%, a PPV of 26.8%, and a NPV of 80.0%, while the positive likelihood ratio 1.15 with an overall accuracy of 62.2%. The ROC curves constructed an AUC of 0.701 with 95% CI, 0.561-0.841 (see Figure 5). The correlation between PIP and PPG was high correlation (see Figure 6).

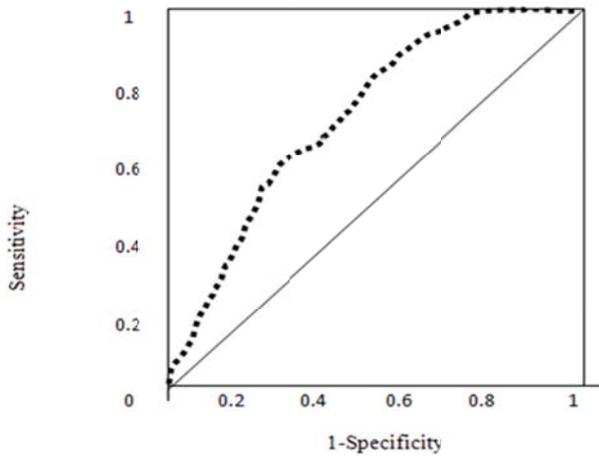


Figure 4. Peak interface pressures receiver operator characteristic (ROC) curve. The ROC curve plot of sensitivity and 1-specificity or each possible score of the peak interface pressure; the area under curve (AUC) was 0.658 (confidence interval, 0.490-0.826).

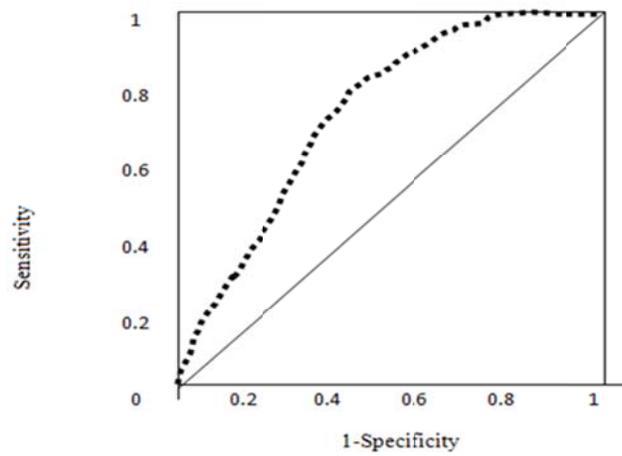


Figure 5. Peak pressures gradient receiver operator characteristic (ROC) curve. The ROC curve plot of sensitivity and 1-specificity or each possible score of the peak pressures gradient; the area under curve (AUC) was 0.701 (confidence interval, 0.561-0.841).

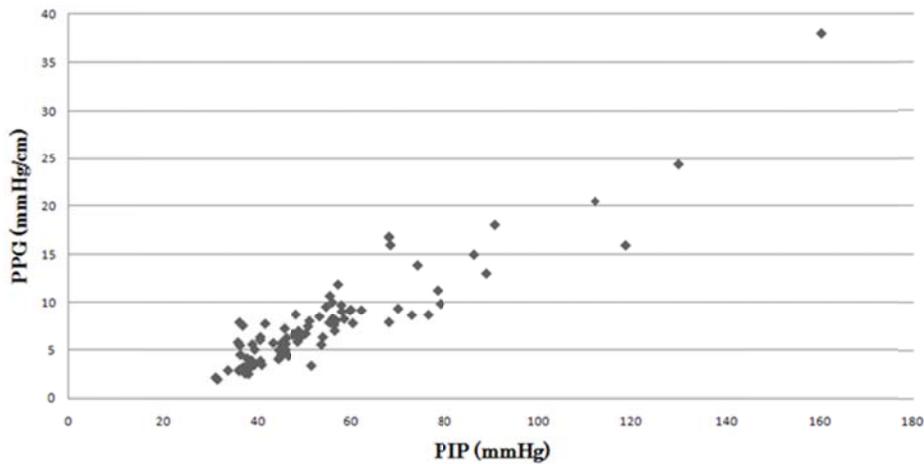


Figure 6. Correlation between peak interface pressure (PIP) and peak pressure gradient (PPG; $r = 0.925$)

4 Discussion

The incidence of pressure ulcers in this study was 12.6%. The incidence in this study was lower than that reported in previous study in Indonesia [1]. This may be explained by the fact that the current study was conducted in an intensive care unit which used air and foam mattresses and the previous study used standard mattresses made in Indonesia. The risk of developing a pressure ulcer for patients who use standard mattresses is high [1].

The research showed that PIP and PPG values were significantly higher with pressure ulcers than without pressure ulcers. PIP and PPG had a very strong relationship to predict pressure ulcer development. This research found that PIP and PPG were important risk factors that contribute to pressure ulcer development.

Okuwa *et al.* [13] that research used the same instrument for elderly people patients with our research. A cut-off value 50 mmHg has been used for prediction of patients at risk of developing pressure ulcers in ICU. However, the findings of the

current study do not support the *previous research that was reported by Suriadi et al.* [2]. There is a reason that there are differences in the tools used for measurement of IP. Our research used a multi-pad with five sensors, whereas in previous studies a multi-pad with three sensors were used, a multi pad three sensors have smaller size than five sensors, so five sensors can measure of sacrum or buttock wider area and the coefficient of variance was 8.96%. The precision of the replicates in the current study was not different with respect to the way the replicates or individual tests were performed. Another study also postulated that IP is a factor in pressure ulcer development [17].

The current study showed that the predictive validity of PIP by a ROC curve was weak, but a PIP value of 50.0 mmHg with sensitivity, specificity, and PPV was a lower value and the NPV was highest and the accuracy of the PIP (59.8%). NPV was the highest value, which indicates that the probability of patients with no pressure ulcer development. Thus, a PIP (≤ 50.0 mmHg) was not predictive of the risk of pressure ulcer development, but PIP > 50.0 mmHg was predictive of the risk pressure ulcer development.

The research showed that the PPG was adequate with pressure ulcer development compared to no pressure ulcer development. The current study showed that a PPG of the 8.0 mmHg/cm was not predictive for pressure ulcer development but PPG more than 8.0mmHg/cm was predictive for pressure ulcer development. Mueller MJ *et al.* [10] reported that the average of PPG was 143% substantially higher in the front of the foot than in the rear of the foot and the PPG was substantially higher and may be a useful indicator of skin trauma because spatial changes in high plantar pressures may identify high stress concentrations within the soft tissue. The concept of a Pressure Gradient contributing to potentially harmful internal stresses has been conducted [11]. A large change in pressure across the surface of the skin (a high PPG) may result in an excessive internal stress response [18] and resultant shearing of soft tissues that may contribute to tissue injury and breakdown [19]. There are no previous studies investigating PPG with and without pressure ulcer development. Interestingly, PPG was the only pressure variable in this study that distinguished patients with and without pressure ulcer development. Our research provides data on the relationship between the PPG with the development of pressure ulcers, although not as an indicator of the development of pressure ulcers that occur in the clinical setting.

Potential limitations of this research that require further consideration include that this research was an assessment of pressure ulcers focused on the sacrum only. Body shape and weight the patient's, skin condition, medical condition and variables associated with care are outside the scope of this study.

5 Conclusion

The research showed that the incidence of pressure ulcers of both hospitals was 12.6% at the sacrum and buttocks. This study indicates that a significance difference exists between PIP and PPG with pressure ulcer development and no pressure ulcer development. The PIP and PPG may be a useful indicator for *predicting* the development of *pressure ulcers* between patients with and *without pressure ulcers*. This may reduce the costs (human and fiscal) of patient care and also the institution, which will be an incentive to promote future research in the prevention of pressure ulcers in a clinical setting. In this study it was postulated that IP and PG evaluators that were identified to predict pressure ulcer development, so the tools can be used to prevent the development of pressure ulcer risk in patients and as a nursing intervention assessment. This is a new assessment for predicting pressure ulcer using PG evaluator and it is effective to screen ICU patients who have no risk of pressure ulcer. The results of this study can improve nursing care by performing measurements on the body surface between the mattress by means of tilt left and right to prevent pressure sores.

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