Discussion on Comparative Results:

Comparison of Transcutaneous Oxygen Tension ($TcPO_2$) and Transcutaneous Carbon Dioxide Tension ($TcPCO_2$) in Patients with a High- and Low- Risk of Pressure Injury

The National Pressure Ulcer Advisory Panel (NPUAP) announced a change in terminology from pressure ulcer to pressure injury in 2016 (1). $TcPO_2$ and $TcPCO_2$ monitoring may serve as an objective, effective and non-invasive tool for assessing the risk of pressure injury. The comparison of $TcPO_2$ and $TcPCO_2$ in patients with a high and low risk of pressure injury will provide a valuable reference for future research in $TcPO_2$ and $TcPCO_2$ studies. Thus, we provide the discussion on the comparison of $TcPO_2$ and $TcPCO_2$ in patients with a high and low risk of pressure injury based on the results in our study described in our paper.

1. **No statistically significant difference in tissue perfusion between sacrococcygeal regions and anterior chest when the sacrococcygeal regions bear no pressure**

The results of this study show that, whether the risk of patients predicted by Braden pressure sore is high or low, there is no statistically significant difference in tissue perfusion between sacrococcygeal regions and anterior chest when the sacrococcygeal regions bear no pressure (Table 1). This result suggests that the $TcPO_2$ (and $TcPCO_2$) in the sacrococcygeal regions may represent that in the anterior chest when the sacrococcygeal regions bear no pressure. $TcPO_2$ and $TcPCO_2$ monitoring is a local non-invasive testing method by heating the electrodes connected to the measuring site to arterialize the local capillaries and disperse the gas to the skin surface. It can reflect the oxygen supply of body to the tissues in real time and continuously. Studies have shown that in adults when blood vessels furthest dilate, the arterial partial pressure of oxygen is very close to $TcPO_2$ (2) . $TcPO_2$ depends on respiratory function, function of transport of oxygen in the blood, and circulatory function. Because the skin is at the end of the body's oxygen supply system, any damage to any part of the body's oxygen supply can be immediately reflected by $TcPO_2$ changes. $TcPO_2$ is objectively used to assess the activity of skin tissue under various clinical conditions (3,4).

In a comparative study (5), $TcPO_2$ was found to be the most repeatable and convenient method to assess the activity of the tissue after being pressed. The research reported (6) that $TcPO_2$ values in normal subjects' chest (the second intercostal space) ranged from 50-95mmHg and their mean values were 69 ± 11mmHg. In this study, the $TcPO_2$ values of the chests in the

high-risk group in pressure injury were 73.03 ± 22.84mmHg, and $TcPO_2$ values of the chests in the low-risk group were 69.80 ± 22.36mmHg, which was similar to that research reported. The chest skin is the best part of blood circulation in the whole body, and the sacrococcygeal pressure injury is high-incidence part in the whole body. In this study, in both the high- and low-risk groups in pressure injury, no significant difference of $TcPO_2$ and $TcPCO_2$ between anterior chest and sacrococcygeal region is found when sacrococcygeal regions bear no pressure, which is also consistent with that in normal people. Pressure is the main cause for patients who have a pressure injury, and changes in $TcPO_2$ and $TcPCO_2$ may reflect the effect of pressure on the skin tissue.

2. **No significant difference of $TcPO_2$ and $TcPCO_2$ in sacrococcygeal regions between the patients with a high and low risk when their sacrococcygeal regions also bear no pressure**

When continuous pressure acts on local skin, it causes low perfusion of the local tissue, resulting in decreased blood flow velocity, hypoxia, acidosis, interstitial hemorrhage, cell death, pressure injury, decreased PO_2 pressure and increased CO_2 pressure of local skin. Low perfusion also stimulates local inflammatory responses and aggravates tissue damage. The extent of damage is related to stress duration and strength. If the compressed tissue has regenerative capacity, it can lead to PO_2 pressure increase and PCO_2 decrease in the tissue (7) through the patient's independent activity to make the pressure removal, capillary re-expansion, local blood flow increase and reactive hyperemia (8). The patients who are cognitively integrated and have voluntary activity suffer from low perfusion of local tissue, and will move autonomously and reduce discomfort. Low perfusion will continue in the patients who suffer from impaired cognition until they are helped to change their posture. Therefore, it is an important content in the risk assessment of pressure injury to assess whether the patients have the ability of voluntary movement (9).

At present, the clinically commonly used is the Braden scale as the pressure injury assessment scale. The scale evaluates pressure injury risk in patients from 6 aspects of perception ability, moist degree, ability of movement, locomotivity, nutrient uptake capacity, friction force and shear force, which is also related to the patients' "ability of movement". The "ability of movement" in the scale refers to the degree of movement ability, including 4 degrees of lying in bed, sitting on chair, occasional walking, and frequent walking, which is unable to assess

whether the patients have the ability of autonomic movement. Although some patients are bedridden, their ability of autonomic movement in the bed does not reduce. The study finds that there is no difference in $TcPO_2$ and $TcPCO_2$ values of sacrococcygeal regions between the high- and low- risk groups in pressure injury when the sacrococcygeal regions are not pressed. Meanwhile, this study also shows that $TcPO_2$ values of sacrococcygeal regions in the high-risk group in pressure injury are significantly lower than that in the low-risk group when sacrococcygeal regions bear pressure, while $TcPCO_2$ values are higher than the low-risk patients (Table 2). Therefore, the high-risk patients assessed by the Braden scale do not always continue to be at a high risk, and when the sacrococcygeal regions of high-risk patients bear no pressure, they have the same perfusion of local tissue as those low-risk patients.

Meanwhile, this study shows that $TcPO_2$ values of sacrococcygeal regions in the high-risk group in pressure injury are significantly lower than that in the low-risk group when sacrococcygeal regions bear pressure, while $TcPCO_2$ values are higher than the low-risk patients (Table 2). That is to say, only when their sacrococcygeal regions are under pressure, the high-risk patients are truly at high risk and their tissue perfusion is not the same as those of low-risk patients, which suggests that $TcPO_2$ and $TcPCO_2$ are both sensitive to the status of the risk of pressure injury. Therefore, when $TcPO_2$ and $TcPCO_2$ are used to evaluate skin tissue perfusion, they are better to distinguish the risk of pressure injury in patients. It is also suggested that they must assess the ability of autonomic movement when conduct the assessment of the risk of pressure injury in patients. In this study, the range of Braden score in patients with high-risk pressure sores is 7-12 points, while the range of $TcPO_2$ is 0-105mmHg and range of $TcPCO_2$ is 28-122mmHg, and the change of $TcPO_2$ and $TcPCO_2$ values are far greater than Braden scores after sacrococcygeal regions being pressed. Thus, $TcPO_2$ and $TcPCO_2$ can provide clinical guidance for the conditions of tissue perfusion of different individuals after sacrococcygeal regions being pressed, which is consistent with research reports (10).

3. In patients with high-risk and low-risk pressure injury, $TcPO_2$ decreases and $TcPCO_2$ increases when their sacrococcygeal regions bear pressure

When the pressure continues to act on local skin, it causes low perfusion of local tissue, then resulting in slow blood flow velocity, hypoxia, acidosis, interstitial hemorrhage, cell death, decrease of $TcPO_2$ and increase of $TcPCO_2$ of local skin. The results of this study show that both

groups of patients suffered from decrease of $TcPO_2$ and increase of $TcPCO_2$ after sacrococcygeal regions being pressed (Table 3), which is consistent with the pathophysiological mechanism of skin injury. This result confirms that the values of $TcPO_2$ and $TcPCO_2$ are sensitive to the change of pressure imposed on the measured region. $PaCO_2$ fluctuates normally in 36~44mmHg, and in this range, the tissue can remain normal activity. Elevated $TcPCO_2$ is caused by accumulation of toxic metabolites and is of no benefit to tissue activity. When the pressure continues to affect local tissue, the blood flow of the tissue will be completely blocked, and $TcPO_2$ will drop to 0 (5). In other words, the lower $TcPO_2$, the more severe ischemia and hypoxia in the sites, and the more severe damage is. It is reported by the research (10) that when the $TcPO_2$ of skin tissue drops to 20mmHg, the required contact pressure is between 27-108mmHg. External pressure produces interstitial pressure, and if the interstitial pressure exceeds capillary pressure (the capillary pressure is usually considered to be 32mmHg), tissue ischemia will occur (10). In this study, the $TcPO_2$ in the high-risk group was 15.66 $\pm$ 5.17mmHg with pressure of sacrococcygeal regions of least 30mmHg and tissue ischemia in sacrococcygeal regions, so they are more prone to have pressure injury compared to the low-risk group.

4. **The magnitude of change of $TcPO_2$ and $TcPCO_2$ is higher in the patients with a high risk than in those with a low risk of pressure injury.**

The results of this study show that both groups of patients suffered from decrease of $TcPO_2$ and increase of $TcPCO_2$ after sacrococcygeal regions being pressed (Table 3), which is consistent with the pathophysiological mechanism of skin injury. This result confirms that the values of $TcPO_2$ and $TcPCO_2$ are sensitive to the change of pressure imposed on the measured region. Elevated $TcPCO_2$ is caused by accumulation of toxic metabolites and is of no benefit to tissue activity. When the pressure continues to affect local tissue, the blood flow of the tissue will be completely blocked, and $TcPO_2$ will drop to 0 (5). In other words, the lower $TcPO_2$, the more severe ischemia and hypoxia in the sites, and the more severe damage is.

Although the results show that both the high-risk and low-risk groups have decreased $TcPO_2$ and elevated $TcPCO_2$ after sacrococcygeal regions being pressed, the reduction of $TcPO_2$ and the increase of $TcPCO_2$ in the two groups are not consistent. The change The reduction of $TcPO_2$ and the increase of $TcPCO_2$ in the high-risk group is more obvious than that in the low-risk group, which is statistically significant (Table 4). In another word, the magnitude of change

of $TcPO_2$ and $TcPCO_2$ is higher in the patients with a high risk than in those with a low risk of pressure injury. This is a good property for using $TcPO_2$ and $TcPCO_2$ to assess the risk of pressure injury because an effective metric for assessing the risk of pressure injury should have a higher magnitude of change to the same amount of pressure in a patient with a high risk than a patient with a low risk so that it matches with the fact that the same amount of pressure will lead to a higher risk of injury to a patient with a high risk than to a patient with a low risk.

To explore the magnitude of change in more details, it was reported by the research (11) that $TcPO_2$ decreased by more than 60%, the risk of damage to soft tissue activity would increase, and if $TcPO_2$ decreased by more than 90%, the risk of damage to soft tissue activity would certainly increase. This study shows that in high-risk patients of pressure injury with sacrococcygeal pressure, $TcPO_2$ decreases 58.31 ± 20.80mmHg, by 79%, and the risk of sacrococcygeal skin damage increases; and in the low-risk group of patients with $TcPO_2$ decreases 36.73 ± 9.21mmHg, by 56%, with a lower risk of sacrococcygeal skin injury. Although there is no literature on the effect of increased $TcPCO_2$ on soft tissue activity, the results show that $TcPCO_2$ increases by 75% in the high-risk group after sacrococcygeal regions being pressed, and $TcPCO_2$ increases by 24% in the low-risk group. $TcPCO_2$ has a better sensitivity of risk of damage to soft tissue activity in patients than that of $TcPO_2$.

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