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SKIN BLOOD FLOW IN RELATION TO EXTERNAL PRESSURE AND TEMPERATURE IN THE SUPINE POSITION ON A STANDARD HOSPITAL MATTRESS

Anna-Christina Ek, Gunilla Gustavsson and David H. Lewis

From the Clinical Research Center, University Hospital, S-581 85 Linköping, Sweden

ABSTRACT. The purpose of this investigation was to study the relationship between skin blood flow, external pressure and temperature in the skin over bony prominences and muscle padded areas, when healthy individuals and patients with hemiplegia were lying in the supine position on a standard hospital mattress. The pressure values under the gluteus maximus muscle and the sacrum increased significantly in the supine position with bent knees. The heels resting on the mattress gave very high pressure values. Some patients had no observable skin blood flow in the skin over the sacrum and the gluteus maximus muscle. In many individuals there was no observable blood flow in the skin over the heel among both healthy individuals and patients, which was confirmed by very high post-ischemic reactive hyperaemia. There is also a heat accumulation when lying on the mattress which increases the requirement for skin blood flow.

Key words: pressure sore, pressure, skin blood flow, skin temperature, reactive hyperaemia.

The effect of the duration of external pressure on tissues has been studied in animal experiments (4, 5, 9). Microscopic changes in the tissue and changes in the tissue blood flow occur after pressure induced ischemia. After 2 hours of ischemia the changes were reversible but after 4 hours of ischemia they were irreversible (9). Ischemia combined with increased temperature aggravated the changes (8). Pressure induced ischemia is said to depend upon interruption of the skin blood flow, but ischemia can also occur if the blood flow is insufficient in relation to the demands.

The pressure values obtained in the supine position have been measured in experimental beds with softer and stiffer springs. The values were lower in the beds with softer springs and no values were higher than 60 mmHg (6), which is the upper limit of the external critical pressure values, said to range between 30 and 60 mmHg (5, 7).

The skin oxygen tension decreases under increasing (0–250 mmHg) applied pressure, more in skin over bony prominences than over muscle-padded areas (10). This supports the hypothesis that the skin blood flow is insufficient, when the skin is exposed to pressure.

Heat is accumulated between the human body and the supporting surface (9). This higher temperature requires higher skin blood flow in order to remove the heat, and also to meet the increased metabolic demand of the tissue.

The purpose of this investigation was to study the relationship between skin blood flow, external pressure and temperature in the skin over bony prominences (sacrum and heel) and muscle padded areas (gluteus maximus), when healthy individuals and patients with hemiplegia were lying in the supine position on a standard hospital mattress.

MATERIAL AND METHODS

The measurements were carried out on 11 healthy individuals, 6 women and 5 men. Mean age was 39.2 ± SD 11.6. The measurements were also carried out on 21 patients with partial or total hemiplegia of whom 10 were women and 11 men; 7 had hemiplegia on the right side and 14 on the left. Mean age was 76.6 ± SD 5 years.

A Flatline Load Cell ELF-EA-25-5 (Entran International) was used to measure the pressure between the individual and the standard hospital mattress. The load cell is a semiconductor strain gauge device, 25 mm in diameter, 4 mm in thickness with a hole in the centre 6.5 mm in diameter which allows measurement of the skin blood flow simultaneously. The range was 5 daN and the sensitivity 1 023 mV/daN. The load cell surface was covered with a transparent plastic 1 mm in thickness, so as to have that distance between the skin and the flowmeter.

The skin blood flow was measured with the laser Doppler flowmeter Periflux 1d with full scale 10 V (Perimed, Stockholm, Sweden). Laser Doppler flowmetry is a non-invasive technique that measures the velocity of the moving red cells to a depth of approximately 1 mm. This technique gives a measure in millivolts which is linearly related to the blood flow (12). The load cell and the flowmetry curves were inscribed on a two channel recorder (Omniscribe® Houston Instrument).

Table I. *Skin temperature (°C) measured with the individuals in the lateral position and after 5 min in the supine position*

	Healthy persons (n=11)		Patients (n=21)	
	Lateral pos. $M \pm$ SD	Supine pos. $M \pm$ SD	Lateral pos. $M \pm$ SD	Supine pos. $M \pm$ SD
Sacrum	32.5±1.1	33.4±1.0***	32.5±1.8	33.8±1.3***
M. gluteus maximus	31.5±1.4	32.8±1.1**		
Paretic side			31.5±2.4	33.6±1.5***
Non-paretic side			31.4±2.0	34.0±1.4***
Heel	30.2±2.5	31.9±2.1**		
Paretic side			26.7±2.3	28.9±2.5***
Non-paretic side			27.1±2.2	28.8±2.1***

** $p<0.01$, *** $p<0.001$.

The skin temperature and the ambient temperature were measured with a thermistor temperature probe (Yellow Springs Instrument Co., Yellow Springs, Ohio, USA). The skin temperature was noted on the paper initially and every fifth minute thereafter.

The standard mattress (10 cm in thickness, polyester) was prepared with five hollows 25 mm in diameter and 4 mm in depth. In the centre of these hollows was a channel 7 mm in diameter made to allow the laser Doppler probe to penetrate the mattress. These hollows were situated under the sacrum, the gluteus maximus muscle and the heel.

A standard bedstead was used. The mattress was covered with a thin transparent plastic drawsheet in which a hole was made for the probe and the load cell. The sheets covered the mattress; a pillow and a top sheet completed the bed.

The observations began with measuring the basal blood flow in two places in the skin over the sacrum, the gluteus maximus muscle and the heel with the individual in the lateral position to obtain a mean of the skin blood flow in each region. The skin temperature was also measured. The measuring devices were placed in the hollows in the mattress one at a time with the temperature probe beside the load cell and then the person lay down.

In all cases the measurements were made first under the sacrum, then under gluteus maximus muscle and finally under the heel. The measurements were first made with the person in the outstretched supine position. Then when measuring under the sacrum and gluteus maximus muscle, the persons were asked to bend their knees. Reactive hyperaemia was measured immediately (less than 30 sec) after unloading with the person in the lateral position. The height and weight were noted and the arm blood pressure was measured.

The healthy individuals were measured unilaterally and the patients with hemiplegia were measured bilaterally. All measurements in the supine outstretched position reported were read after 5 min. The observations in the supine position with bent knees were read after an additional 2–3 min in supine position.

Statistical methods used in this study were arithmetic means, standard deviation, Student's t-test, Wilcoxon matched-pairs signed-ranks test and regression analysis. In patients the relation between skin blood flow during the supine position as the dependent variable and skin blood flow before loading, skin temperature, external pressure, arm blood pressure, weight, height and ambient temperature as the independent variables were analysed.

RESULTS

Skin temperature

Healthy individuals had a significantly higher skin temperature on the heel in the lateral position before loading than the patients had ($p<0.01$). The differences in skin temperature between the paretic side and the non-paretic side in the parents were not statistically significant ($p>0.05$). When comparing the skin temperature in the lateral position with those in the supine position, the differences were however statistically significant in both groups ($p<0.001$) (Table I).

External pressure

The external pressure values obtained between the standard mattress and the sacrum in the healthy individuals were lower than those obtained under the patients ($p<0.01$) and the values obtained under gluteus maximus muscle and the heel were higher when comparing the healthy persons with the patients ($p<0.01$). The differences observed in external pressure between the paretic side and the non-paretic side in the patients were not statistically significant ($p>0.05$) (Fig. 1). However, the pressure values obtained under the sacrum and the gluteus maximus muscle increased when the persons were lying with bent knees compared with the outstretched position ($p<0.01$) (Table II).

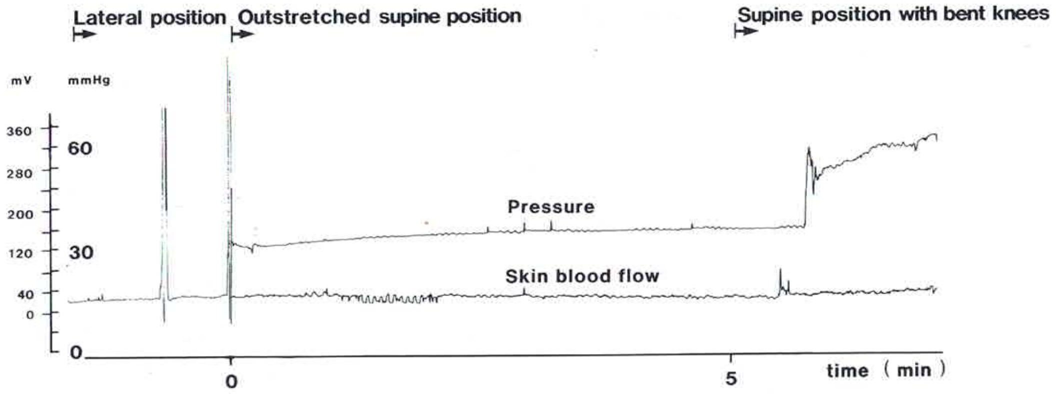

Fig. 1. The relative blood flow in the skin over the sacrum as measured with the laser Doppler flowmeter and the result expressed in millivolts (mV), with the patients lying first in the lateral position, then in the outstretched supine position and finally in the supine position with bent knees. At the same time the pressure was measured with a flatline load cell and expressed in mmHg during the time the patients were lying in the supine positions.

Skin blood flow

The differences in skin blood flow measured, before, during and after loading were statistically significant only with regard to the heels. However, in four patients skin blood flow ceased at pressure values between 11 and 50 mmHg: one in the skin over the sacrum, one in the skin over the gluteus muscle, paretic side, in the outstretched position and in two the blood flow in the skin over gluteus maximus muscle ceased when they had bent their knees. Two of them had a slight increase in their skin blood flow after loading.

In most cases among the healthy individuals the blood flow curves inscribed from the skin over the heel indicated very low skin blood flow and the curves showed no signs of vasomotion when lying in the outstretched supine position. There was no measurable skin blood flow in nine heels on the paretic side and in eleven heels on the non-paretic side in the patients. Six patients showed no observable skin blood flow bilaterally in the heels in the outstretched supine position (Table III).

In healthy individuals correlation analysis indicated a weak positive correlation between the skin blood flow in sacrum in the supine position and the skin blood flow and skin temperature in the lateral position before loading, and a weak negative correlation with weight index. In the heel there were weak positive correlations between skin blood flow during loading and systolic blood pressure, and a negative correlation with room temperature.

The regression analysis indicated a significant

Table II. *Pressure values (mmHg) obtained when the persons were lying in the stretched supine position and with bent knees*

	Healthy persons (n=11)		Patients (n=21)	
	Outstretched $M \pm$ SD	Bent knees $M \pm$ SD	Outstretched $M \pm$ SD	Bent knees $M \pm$ SD
Sacrum	30.7±9.0**	49.2±17.7**	38.2±13.3	61.2±14.6**
M. gluteus maximus	36.1±12.6**	57.3±21.5**		
Paretic side			23.8±9.9	31.0±15.7**
Non-paretic side			23.1±11.7	33.6±16.7**
Heel	103.1±27.1			
Paretic side			71.7±18.1	
Non-paretic side			74.5±17.2	

** $p<0.01$.

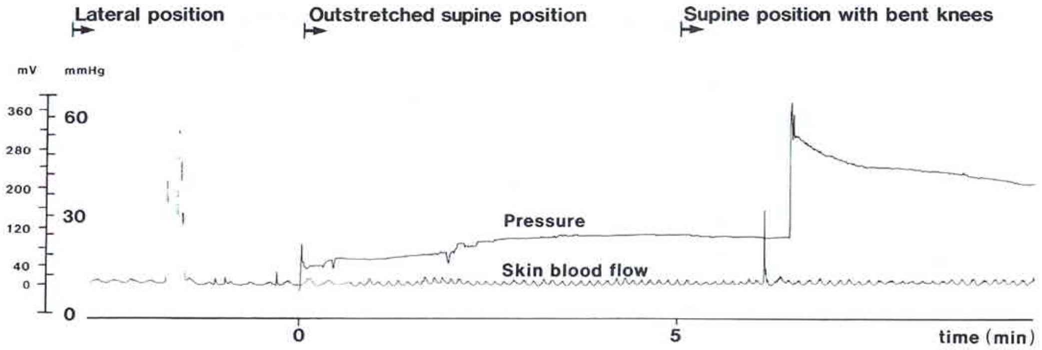

Fig. 2. The relative blood flow in the skin over the gluteus maximus muscle as measured with the laser Doppler flowmeter and expressed in millivolts (mV), with the patients lying first in the lateral position, then in the outstretched supine position and finally in the supine position with bent knees. The pressure was measured with a flatline load cell simultaneously and expressed in mmHg during the time the patients were lying in the supine positions.

negative correlation between the skin blood flow during supine position and room temperature in the sacrum in the group of patients ($p<0.01$).

In the non-paretic heel the regression analysis indicated a significant positive correlation between the skin blood flow and temperature ($p<0.01$) measured between the heel and the mattress and a significant negative correlation with the skin blood flow before loading ($p<0.01$).

In the heel on the paretic side of the body the regression analysis indicated a significant negative correlation between external pressure, weight ($p<0.05$) and skin blood flow before loading ($p<0.01$) and significant positive correlation with weight index ($p<0.05$), height and skin temperature before loading ($p<0.01$).

DISCUSSION

The measuring devices used in this study allow measurements of pressure, relative skin blood flow and skin temperature simultaneously. The devices were sunk into the mattress so as not to influence the results. However, these devices have limitations. The persons could not move in the bed when the load cell and the laser Doppler probe were in the mattress;

Table III. *The ranges in skin blood flow (mV) measured with the laser Doppler flowmeter*

The persons were in the lateral position before and after loading, and in the supine position with stretched and bent knees. Md = median

	Lateral pos., before		Supine pos. Stretched knees		Supine pos. Bent knees		Lateral pos., after	
	Range	Md	Range	Md	Range	Md	Range	Md
Healthy persons								
Sacrum	40–72	45	28–100	46	44–96	64	24–108	40
M. gluteus maximus	36–72	54	40–216	58	48–278	78	–	
Heel	55–464	282	8–24	12			76–752	614
Patients								
Sacrum	20–60	28	0–56	36	0–96	36	12–60	24
M. gluteus maximus								
Paretic side	20–48	24	8–80	20	0–56	22	20–68	28
Non-paretic side	12–60	24	0–80	24	0–64	28	16–108	24
Heel								
Paretic side	40–416	60	0–68	7			76–664	328
Non-paretic side	24–208	68	0–80	0			204–780	392

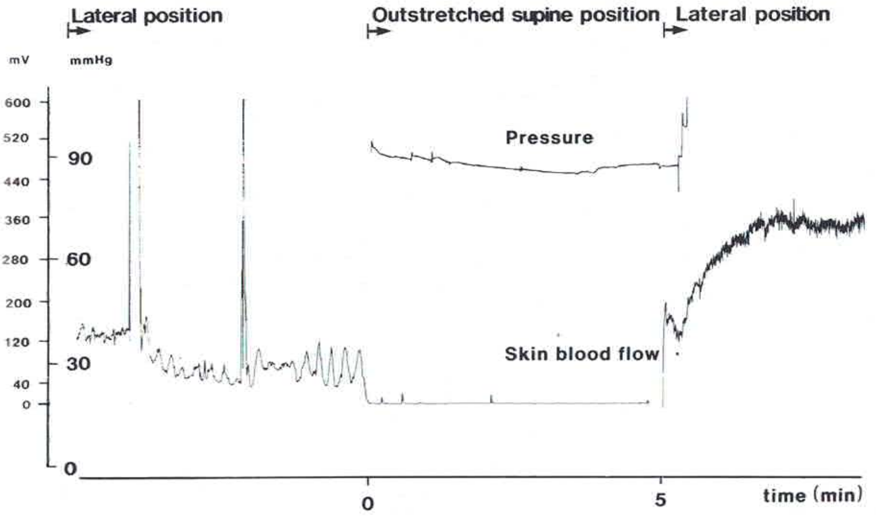

Fig. 3. The relative blood flow in the skin over the heel as measured with the laser Doppler flowmeter and expressed in millivolts (mV) before, during and after the patients were lying in the outstretched supine position. The pressure was measured with a flatline load cell simultaneously and expressed in mmHg when the patients were lying in the supine position. Maximum reactive hyperaemia occurred after approximately 2 min.

the load cell could not stand 100% humidity. These limitations make it difficult to measure over a long period of time.

The temperature measured between the body and the supporting surface was higher than the skin temperature before loading, in the lateral position. Heat is accumulated which increases the metabolic demands in the tissue. This requirement may not be satisfied, due to an impairment in the ability to increase skin blood flow in relation to the heat stimulus in the lower part of the body among elderly patients (2). Even if the skin blood flow does not cease due to pressure, the tissue may suffer from a relative ischemia due to insufficient skin blood flow during prolonged heat accumulation. However, there was no significant increase in the skin blood flow after unloading probably due to a brief time of loading and heat stimulus.

The pressure values obtained when measuring under the sacrum and under the gluteus maximus muscle in this study were in agreement with previously obtained values (6). It is, however, important to stress that with bent knees the pressure becomes much higher than with stretched knees. Many patients in long-term care have contractures with bent knees as a result; those patients have always higher pressure values when lying in the supine position.

The pressure values in the healthy individuals were significantly higher under the gluteus maximus muscle and the heel than in the patients. This could possibly be due to the fact that healthy individuals bear more weight on their gluteus maximus than on their sacrum, which may well be due to their better and more active muscles.

The external pressure values obtained between the heels and the mattress were higher than earlier reported pressure values (6). In many individuals there was no measurable skin blood flow and in all cases ischemia was confirmed by post-ischemic reactive hyperaemia.

The skin blood flow in the sacrum and in the gluteus maximus muscle in the supine position did not differ significantly from the skin blood flow in the lateral position. However, in four patients it ceased at pressure values between 11 and 50 mmHg. This is in agreement with a previous study which demonstrated occlusion of pulsatile arteriolar blood flow in geriatric patients sitting in the horizontal position at pressure values from less than 20 to 120 mmHg. For comparison measurements were also carried out in healthy young men, who occluded their pulsatile blood flow at pressure values exceeding 120 mmHg (1).

Two of the four patients whose skin blood flow ceased in supine position had a slight increase immediately after unloading. The skin blood flow before and after supine position did not differ significantly with regard to sacrum and gluteus maximus muscle when analysing the whole group. Some individuals did, however, react with a slight increase and in some of them this was observable with the naked eye. This impaired reactive hyperaemia both after total ischaemia and after relative ischaemia may be due to impaired peripheral circulatory function after immobilization and bedrest (2, 3). Other investigators have shown an impairment in recirculation after long periods of ischaemia (9).

The skin blood flow in the heels during loading was significantly lower than the skin blood before loading both in the healthy individuals and in the patients.

Comparing the pressure values obtained in this study with the suggested critical pressure values' upper limit of 60 mmHg (5, 7), it could be seen that pressure values exceeding 60 mmHg are those values most likely to change the skin blood flow in both healthy individuals and patients. However, even lower values can stop the blood flow in patients.

There were no significant differences between the paretic side and the non-paretic side. This result was unexpected, but it may be due to the fact that the group of patients with hemiplegia are not homogeneous; the site and the effect of the injury differ between the individuals.

The differences between healthy individuals and patients indicate that evaluation of the possibilities to reduce pressure and minimize other undesirable effects from the mattresses and other supporting surfaces have to be done on patients and not on healthy individuals.

It is very important to support and help patients to change position in bed, both to reduce time with high pressure and to reduce heat accumulation. The heel in outstretched supine position and sacrum and gluteus maximus in supine position with bent knees are the sites when lying in bed, which are exposed to the highest pressure values observed in this investigation.

In this study no specific signs were discovered which could help the staff to select risk-patients. It is still very important to look at every individual as a potential risk-patient with regard to pressure and heat accumulation.

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Address for offprints:

Anna-Christina Ek
Clinical Research Centre
University Hospital
S-581 85 Linköping, Sweden