EVALUATION OF PRESSURE RELIEVING POSTURE ON WHEELCHAIR AND BED

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Abstract: Pressure sores are serious problem for patients with spinal cord injuries (SCI). Many kinds of pressure-relieving cushions have been developed to distribute the weight evenly and widely. In this study, the buttock pressure measurements are carried out on the wheelchair and the Gatch bed. Six parameters are calculated and these parameters are represented on a hexagonal radar plot to evaluate the buttock pressure distribution on the wheelchair. Using the radar plot, it is useful for the medical staffs to instruct SCI's posture on the wheelchair. The high pressure area is observed at the ischial tuberosities on the wheelchair but the high pressure area is observed at the sacro-coccygeal region on the bed.

Keywords: Pressure measurement, Prevention, Pressure sore, Spinal cord injury, Wheelchair cushion, Bed

1. INTRODUCTION

The pressure and the tolerance of tissue are big factors in the development of pressure sores (Kosiac, 1959). Many kinds of pressure-relieving cushions have been developed to distribute the weight evenly and over the widest surface area of the body (Tokuhiro *et al.*, 1990),(Inoue *et al.*, 1990). In rehabilitation medicine, physicians and physical therapists (PTs) assist the patients in selecting wheelchair cushions and they sometimes adjust the cushion if necessary. It is very important for physicians and PTs to evaluate the pressure distribution of the cushion.

D.Brienza et al. suggested that it is not pressure alone but rather the resulting tissue deformation that results in the development of pressure sores (Brienza *et al.*, 1996). L. Conner have reported on tissue deformation using computed tomography (CT) scan (Conner and Clack, 1993); however, these measurements do not adequately assist persons in rehabilitation medicine when selecting or adjusting wheelchair cushions. Another approach, therefore, has been to measure the interface pressure using a pressure mapping system (Martin and Mary, 1993),(Henderson *et al.*, 1994).

The measurement of the buttock pressure distribution was previously carried out in SCI patients using the Tekscan pressure measurement system and the air cushion was the best among the five cushions tested, which were the air cushion, contour cushion, gel cushion, Cubicushion, and urethane foam cushion (Tanimoto *et al.*, 1998). In this study, six parameters are calculated to evaluate the buttock pressure distribution for SCI patients, and these parameters are represented on the radar plot for the medical staffs to instruct SCI's posture on the wheelchair. Moreover, the

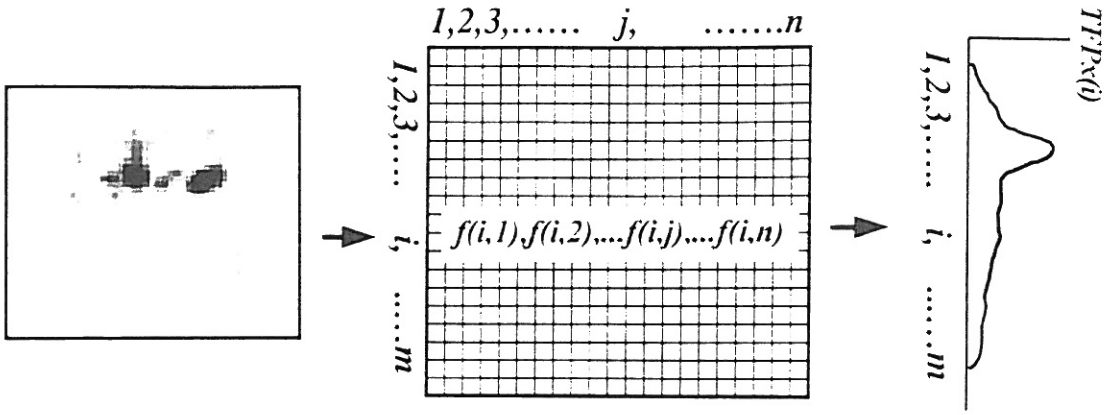


Fig. 1. The method of top five projection.

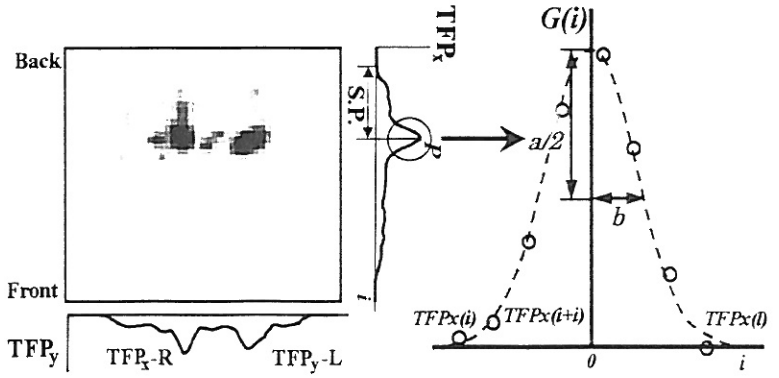


Fig. 2. Horizontal top-five projection, vertical top-five projection and Gaussian curve.

measurement of the buttock pressure distribution on the bed is carried out in healthy subject to evaluate the pressure distribution of some posture on the bed.

2. METHODS

The buttock pressure distribution is measured using the Tekscan "Big-Mat" pressure measurement system. Because a sensor seat consists of 48 pixels x 43 pixels, the buttock pressure is measured at 2,064 points simultaneously with minimal error. This sensor seat is $2mm$ thick and soft, so the measurement of the pressure on soft objects such as cushions and beds is possible. The error caused by creep characteristics is large, so the measurement of the pressure is carried out after patients had sat on the wheelchair cushions for 1 minute to reduce the error (Tanimoto *et al.*, 1998).

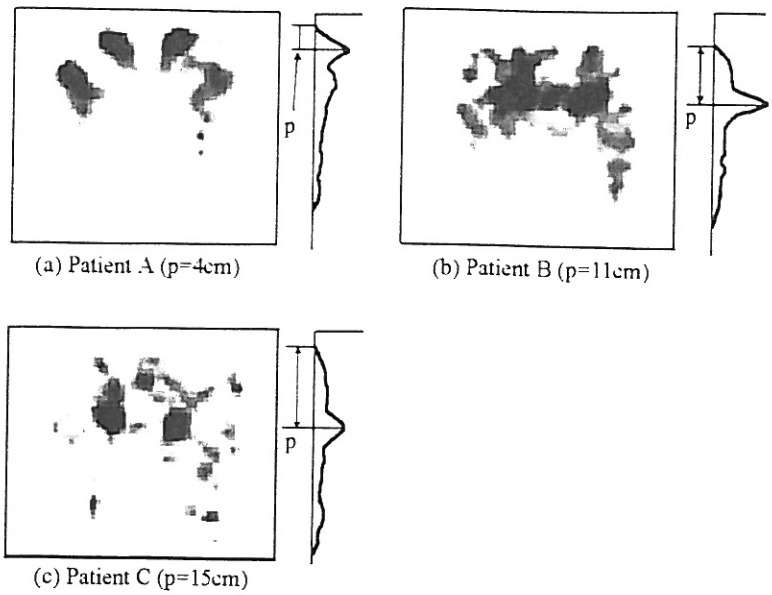
In rehabilitation medicine, the adjustment of the wheelchair cushion is important factor in prevention of pressure sores. To assist medical personnel in evaluating the buttock pressure distribution of SCI patients, the following six parameters are calculated to evaluate the pressure distribution, sitting balance and patient posture on the wheelchair:

(1) maximum pressure (M.P.)
(2) contact area (C.A.)
(3) high-pressure area (H.A.)
(4) tip rate (T.R.)
(5) sitting balance (S.B.)
(6) sitting position (S.P.)

The tip rate, sitting balance and sitting position are calculated from a variable known as the top-five projection. Figure 1 shows the two-dimensional (2-D) representation of the buttock pressure distribution and the horizontal top-five projection, which is calculated as a single value, TFP_x. The horizontal TFP_x is obtained as follows. The pixel values at the i-th horizontal line of an image $f(i,j)$ are rearranged so that they are in decreasing order. The top five pixel values, that is, the largest pixel value $g(i,1)$, the next-largest pixel value $g(i,2)$, ..., and the 5th-largest pixel value $g(i,5)$, are taken from the sorted pixel values. The horizontal top-five projection at the $i-$th line is then defined by

$$TFP_x(i) = \frac{1}{5}\sum_{k=1}^{5} g(i,k). \qquad (1)$$

The horizontal TFP_x is obtained by calculating $TFP_x(i)$ for each horizontal line. Figure 2 shows the horizontal top-five projection TFP_x, the ver-



(a) Patient A (p=4cm)

(b) Patient B (p=11cm)

(c) Patient C (p=15cm)

Fig. 3. Sitting position calculated using top-five projection.

tical top-five projection TFP_y. and an approximate Gaussian curve around the peak point of the TFP_x. The data $TFP_x(1).TFP_x(2).\cdots TFP_x(n)$ as shown in figure 2 are picked up from the TFP_x around the peak point P and are approximated by the Gaussian curve $G(i)$. The tip rate (T.R.) is then defined as

$$T.R. = \frac{1}{2}b/a \tag{2}$$

where a is the peak value of the approximated Gaussian curve and b is defined as

$$G(b) = a/2. \tag{3}$$

The sitting balance (S.B.) is defined by

$$S.B. = \frac{|TFP_y\_R - TFP_y\_L|}{TFP_y\_R + TFP_y\_L} \times 100 \tag{4}$$

where TFP_y_R is the value of the maximum right point in the TFP_y and TFP_y_L is the value of the maximum left point in the TFP_y.

Figure 3 shows the sitting position (S.P.) using the method of TFP. The S.P. is the length between the maximum point of the vertical top five projection(TFP_y) and the back end of the buttock on the buttock pressure distribution. The medical staffs and SCI patients can easily understand the sitting position from this parameter. When the SCI patient sits anteriorly on the wheelchair, the S.P. becomes large. When he sits posteriorly on the wheelchair, the S.P. becomes small. When the SCI patient has large S.B, the high pressure area is observed at the sacro-coccygeal region shown in figure 3 (c). The medical staff has to assist the SCI patients who have high pressure area at sacro-coccygeal region, to hold the posture on the wheelchair carefully.

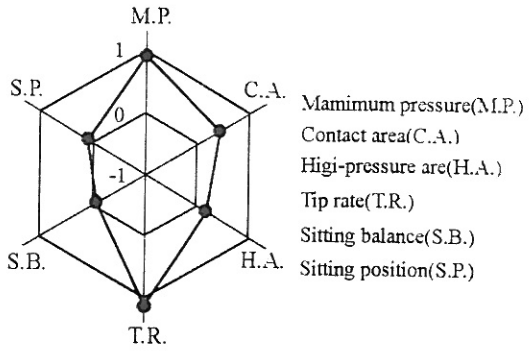


Fig. 4. Hexagonal representation of the parameters.

Figure 4 shows the radar plot that is the hexagonal representation of the six parameters. In this figure, an inner perfect hexagon shows the means of each parameter for 25 SCI patients using the air cushion. Each parameter is put on each axis after normalization with standard deviation of each parameter. The medical staff can understand the position and the approximate size of a high-pressure area from the 2-D representation of the pressure distribution and the exact size of a high-pressure area from H.A. on the radar plot. The T.R. shows the concentration of pressure. When the SCI patient has a large T.R. and M.P., medical staff must select and adjust the cushion carefully. When the SCI patient has a large S.P. on the radar plot, she or he sits anteriorly on the wheelchair. When the SCI patient has large S.B. on the radar plot, the medical staff must assist the SCI patients in maintaining a correct posture.

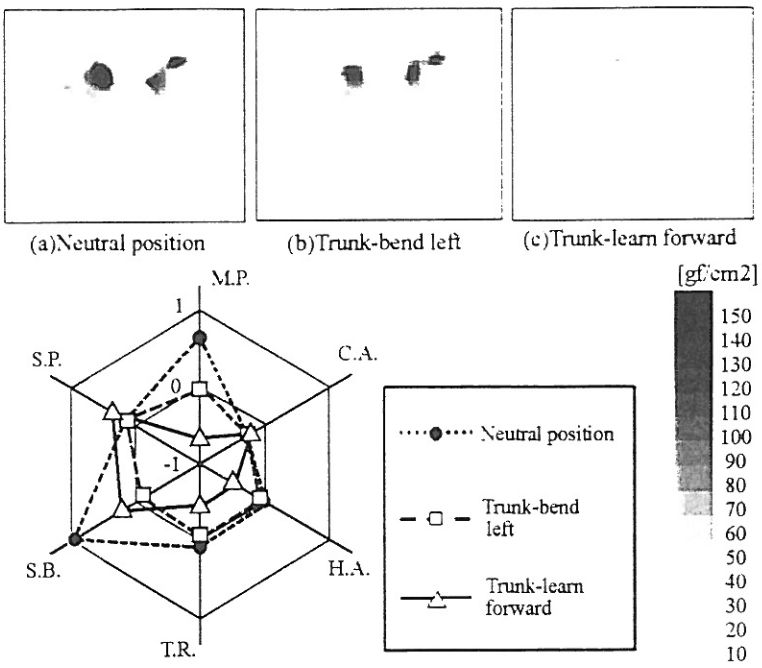


Fig. 6. Two-dimensional pressure distribution and radar plot of three kinds of posture on the wheelchair.

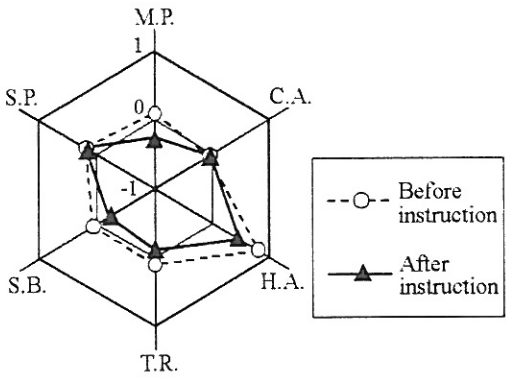


Fig. 5. Hexagonal radar plot when medical staffs instruct patient's posture on the wheelchair.

3. RESULTS

3.1 *Pressure reliving effect of posture on wheelchair*

It is one of the important factors for the medical staff to instruct the SCI patients to hold the posture on the wheelchair. Figure 5 shows the radar plot when the medical staff instructed the SCI patients to hold the posture on the wheelchair evenly. The S.B. become small when the pressure is evenly concentrated on both ischial tuberosities. When the SCI patient has large S.B. on the radar plot, the medical staff has to assist the SCI patients to hold the posture on the wheelchair evenly. When the medical staff instructs the SCI patient to hold the posture on the wheelchair evenly and the SCI patient studies the sitting posture on the wheelchair well, the pressure is concentrated on the both ischial tuberosities evenly. Then the S.B., the M.P., the H.A. and the T.R. become small in figure 5. The maximum pressure changed from $179.1gf/cm^2$ to $130.0gf/cm^2$. In this way, using the radar plot, the effect of the medical staff's instruction of the SCI's sitting posture on the wheelchair is indicated.

In rehabilitation medicine, SCI patients are trained to relieve pressure such as push-ups once every 30 minutes for prevention of pressure sores. However, every SCI patients can't sufficiently push their bodies up on the wheelchair because of the decreased upper extremity strength and endurance. Henderson et al. reported that SCI patients could reduce the pressure on the ischial tuberosities when they inclined the bodies forward with chest close to the thighs(Henderson *et al.*, 1994). Figure 6 shows the effect of the posture change on pressure distribution using the 2-D representation of pressure distribution and the radar plot. Patient is male (Th_6 SCI level) who weighted $66.4kg$. The buttock pressure measurement was carried out in three different positions, neutral position, left-leaning position and forward-leaning position. In neutral position, the S.B. and M.P. was large and the pressure on right ischial tuberosity was $253gf/cm^2$, because his loss of fat and muscles around the right ischial tuberosity. When he leaned left, S.B. became small and the pressure on right ischial tuberosity was $163gf/cm^2$ in figure 6. He inclined the body forward, then M.P., H.A. and T.R. became smaller than that in left-leaning position. The 2-D representation of the pressure distribution and the radar plot that is proposed are useful for SCI patients to understand the effect of pressure relief.

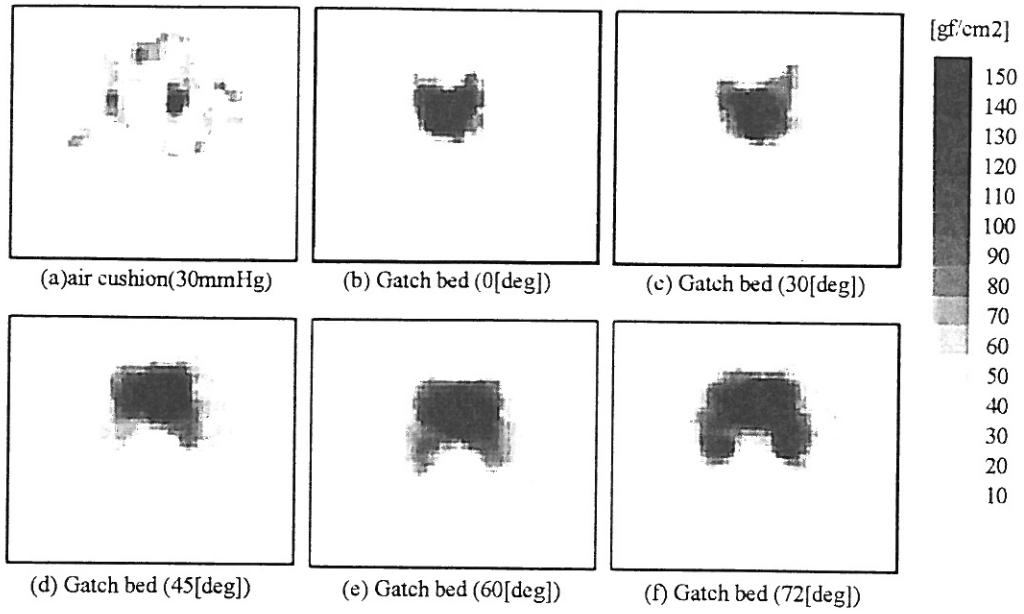


Fig. 8. Two-dimensional pressure distribution of air cushion and Gatch bed.

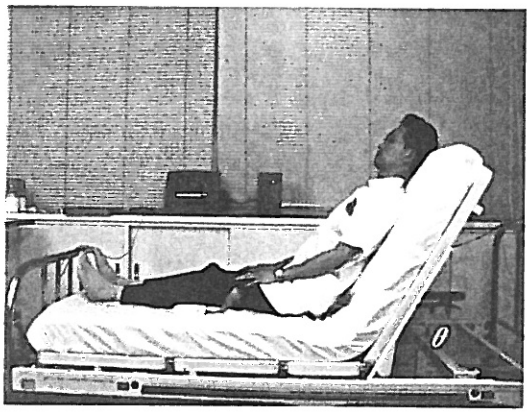


Fig. 7. Sitting posture on the Gatch bed (Gatch bed angle θ equal 60[deg]).

3.2 *Pressure distribution on Gatch bed*

Quadriplegic patients have high risk of developing pressure sores because they sit or lay on the Gatch bed for a long time. Many kinds of mattress have been developed to reduce the interface pressure at particularly susceptible areas(the ischial tuberosities, sacro-coccygeal region and heel) on the bed. They often have meals, read books and write with sitting posture on Gatch bed as shown in figure 7.

The buttock pressure measurements of a health subject were carried out in five kinds of the posture, (Gatch bed angle 0, 30, 45, 60 and 72[deg]) on the Gatch bed using the hard urethane foam mattress. Figure 8 shows the two-dimensional pressure distribution of the air cushion on the wheelchair and the hard urethane foam mattress on the Gatch bed. The high pressure area of the air cushion on the wheelchair is observed at ischial tuberosities. But the high pressure area of the hard urethane foam mattress on the Gatch bed

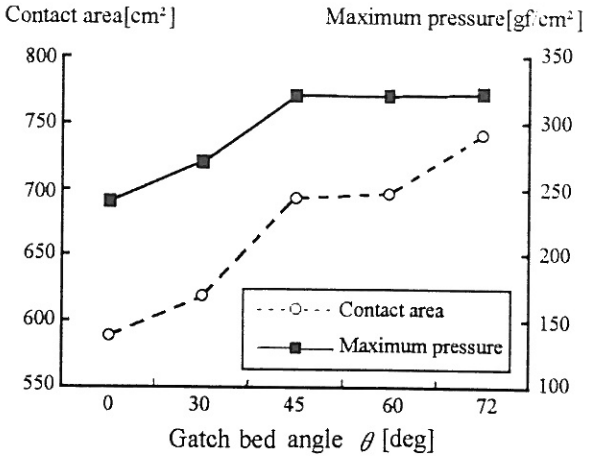


Fig. 9. Contact area and maximum pressure on five kinds of Gatch bed angle.

is observed at sacro-coccygeal region in all five postures. This figure shows that the SCI patients, who spend a long time on the bed, tend to develop the pressure sore at sacro-coccygeal region.

Figure 9 shows the contact area and the maximum pressure on five kinds of posture on the Gatch bed. The contact area and the Gatch bed angle θ have proportional relationship. The maximum pressure of the air cushion on the wheelchair is $152gf/cm^2$, the maximum pressure of the laying posture (Gatch bed angle θ equal 0[deg]) using the hard urethane foam mattress on the Gatch bed is $240gf/cm^2$, and the maximum pressures of the sitting posture (Gatch bed angle θ is more than 45[deg]) are more than $300gf/cm^2$. The maximum pressure of the hard urethane foam mattress on the bad is larger than the maximum pressure of

the air cushion on the wheelchair. Because the pressure at sacro-coccygeal region is large using the hard urethane foam mattress, the medical staffs have to select the mattress and check the skin condition at this regions for quadriplegic patients carefully. The medical staffs and the SCI patients have to take care of sitting time on the Gatch bed, because the maximum pressure in the sitting posture (Gatch bed angle θ is more than 45[deg]) is large.

4. CONCLUSION

In rehabilitation medicine, instruction of the SCI patient's posture is one of the important factors in prevention of pressure sores. In this study, six parameters are calculated and represented these parameters on the radar plot to help medical personnel and SCI patients understand their pressure distribution, sitting position and sitting balance.

Using the radar plot, the medical staff can easily instruct the SCI patient to hold the posture evenly on the wheelchair and SCI patients understand their posture on the wheelchair. It is useful for SCI patients to study their posture on the wheelchair and the prevention of pressure sores.

The maximum pressure of the hard urethane foam mattress on the bad is larger than the maximum pressure of the air cushion on the wheelchair. And the pressure at the sacro-coccygeal region is very large on the Gatch bed . The medical staffs and the SCI patients have to check SCI' skin at sacro-coccygeal region carefully, if the SCI patients spend a long time on the bed. In the future, the measurement of the buttock pressure have to be carried out in many kinds of mattress to suggest the suitable mattress for each SCI patient and instruct the posture on the bed.

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