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A prototype of an automatic mattress turning device: a study of interface pressure at bony prominences in normal subjects

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Abstract

This study was to test an interface pressure at bony prominences when using a prototype of an automatic mattress turning device (AMTD) to reposition a body while lying in a hospital bed. The AMTD consists of a set of air bellows (two large in the middle and two lateral small ones) placed under a 4 inches foam mattress and microcontrollers with air pumps and solenoid valves controlling inflation and deflation of each air bellow. After inflation, it lifted one side of the mattress up so that a body on the mattress turned from supine to a 30° lateral tilt position. Using an XSENSOR pressure mapping system, peak pressure was recorded (mmHg) and peak pressure indexes (PPIs) (mmHg/cm^2) over bony prominences of the body of 20 normal volunteers were calculated and compared between the supine and the 30° lateral tilt positions. In the 30° lateral tilt position, the mean peak pressure reduced significantly at the occiput (30.75, 27.26, $p = 0.003$), the sacroccygeal area (35.99, 27.26, $p < 0.001$) whereas the mean PPIs also reduced significantly at the occiput (21.53 to 14.93, $p < 0.001$), the scapula (21.65 to 18.78, p 0.011), and the sacrococygeal area (33.76 to 27.53, $p = 0.001$). The peak pressure and the PPI were highest at sacrococcygeal area in supine and decreased significantly when a body was turned to a 30° lateral tilt with this automatic mattress turning device.

Keywords: interface pressure, assistive device, repositioning, pressure ulcer, automatic mattress turning device

1. Introduction

Pressure ulcer (PrU), now frequently called "pressure injury" is a common complication among bed-ridden individuals such as those with spinal cord injury (SCI) while staying at hospitals, home and long-term care facilities. Referred to prospective studies, 32 out of 126 (25.4%) SCI patients admitted at the Swiss Paraplegic Center Nottwill with no PrU at admission developed PrUs, and 23 out of 59 (39%) patients admitted with PrU developed additional PrUs during hospitalization [1]; from a multicenter prospective cohort study in the Netherlands, the occurrence of PrUs including stage 1 was 36.5% during acute SCI rehab phase and 39.4% during functional rehabilitation [2]; and a multicenter prospective study in Thailand reported that 14 out of 115 (12.2%) new SCI patients developed PrUs during admission [3]. In addition, among individuals with SCI, the greatest estimated lost life expectancy was associated with chronic PrUs [4].

PrUs usually develop at a heel, sacrococcygeal area, and scapula in a supine position; and over ribs, greater trochanter and malleolus in a side-lying position [2]. Therefore, pressure relief and twice daily skin check are recommended for those at risk [5]. When lying in bed, repositioning every 2-4 hours reduces duration and magnitude of pressure over the bony prominences of the body [5]. Its frequency is based on an individual's tissue tolerance, activity and mobility, medical conditions, skin condition and comfort [5]. To assist in pressure redistribution, a high-specification foam mattress is recommended for those with high risk of pressure injury e.g., significantly limited mobility, inability to reposition oneself, a previous or current PrU [5]. However, turning from supine to the recommended 30° lateral tilt position is still necessary and usually done manually by nursing staff or carers [5 & 6]. A 90 lateral tilt position should be avoided as it increases an interface pressure over the greater trochanter [7]. Another preventive measure is using an appropriate bed to assist turning such as a turning-tilting bed (the Egerton-Stoke Mandeville bed) [8], a lateral rotation bed, an automatic turning bed and a continuous lateral turning bed [9]. However, these special turning/rotation beds are too costly and not available in low- and middle- income countries (LMICs).

At our hospital, a tertiary care hospital, mattresses used are usually made of standard or mixed foam of various density and hardness. An air-alternating overlay is available but used in some wards such as rehabilitation ward where admitted patients are at high risk. Without a special turning/rotation bed, a manual turning and repositioning is practiced. According to a study at a tertiary hospital in Thailand, more than 85% of nurses and nurse-aids developed low back pain after starting work, and it related to activities such as bending, pulling/pushing, lifting and twisting [10]. In addition, one study showed that manual repositioning in bed by nurses, peak pressure over bony prominence varied [11]. Based on a study of the Turn Assist, an air-powered mattress used in intensive care unit (ICU) beds in developed countries, it significantly reduced spine loading and pull force for turning and laterally repositioning when compared with manual lateral reposition [12]. With such concept, we invented a low-cost automatic mattress turning device (AMTD) with a set of air bellows placed beneath a hospital mattress to assist lateral turning and repositioning. After a laboratory test [13], we conducted this study in normal individuals to test and report its effectiveness in interface pressure reduction over bony prominences between the supine and the 30° lateral tilt positions before commercial production.

2. Materials and methods

2.1 Study population

Twenty volunteers, aged over 18 years old, no neurological deficit, no physical limitation, tolerated lying still for at least an hour

2.2 Materials

- The prototype of AMTD consisted of a set of air bellows (two large ones of 190 x 90 cm connected 15 cm apart in the middle, and two small ones of 190 x 25 cm stitched laterally over the large one); and microcontrollers with air pumps and solenoid valves controlling inflation and deflation of each air bellow [13]. The set of air bellows was placed under a mattress. The large air bellow on one side and the opposite small one were simultaneously inflated to lift one side of the mattress up so that a body lying on the mattress was turned from supine to lateral tilt position as shown in Figure 1. According to a 72-hour test with a dummy weighted 47 kg and 147 cm high, equivalent to a body mass index (BMI) of 21.76 kg/cm^2 on a foam mattress, it functioned continuously and efficiently in turning the dummy from supine to a 30° right or left lateral tilt positions. Each position could be maintained from 0 to 120 minutes. In addition, it was tested in a 30° head up position for 24 hours, and all airbags were still functioned normally [13].
- A hospital bed and a mattress (Liberty neo, Lundal Corporation)
- An XSENSOR pressure mapping: X3 series medical version 5.0 with a full-body mattress sensor pad (model PX100: 26.64.01) and sensing area of 77.5 x 203 cm placed over the mattress.
- A foam pillow supporting head, a piece of rectangular foam of 45 x 20 x 3 cm supporting calves and knees in slightly flexed position and another piece of rectangular foam with two-curve surface supporting both ankles and lifting both heels off the mattress.

2.3 Methods

(1) After receiving an approval from the ethic committee (study code: REH-2558-0383), the study was conducted; and each subject was informed and signed an informed consent.
(2) The subjects'gender, age, weight and height were measured and recorded.
(3) The air bellows of the AMTD were simultaneously and slowly inflated, 15 minutes to the right large air bellow and 5 minutes to the left small one, so that the right lateral part of the mattress was lift up and the subject was turned to a required 30° left lateral tilt position.
(4) After maintaining at the 30° left lateral tilt position for 5 minutes and the peak pressure was indentified and recorded over the occipital area, the spine of the scapula, the sacrococcygeal area, and the left greater trochanter. The interface pressures (IP) over the malleoli and the heels were not recorded as both ankles were fully supported with two pieces of foam mentioned above.
(5) In the supine position, the peak pressure point over each bony prominence was recorded (mmHg) and its surrounding area of 9 cm^2 was identified. Peak pressure indexes (PPIs) (mmHg/cm^2) over bony prominences were then calculated [14].
(6) Using the same area over each bony prominence in the supine position, the peak pressure points while being in the 30° left side-lying position were identified and recorded and the PPIs were calculated.

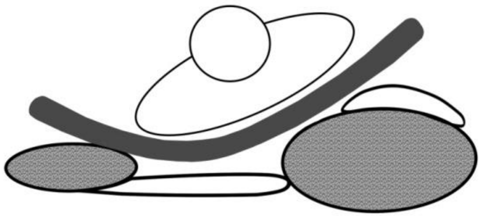

Figure 1 A cross-section diagram of the automatic mattress turning device (AMTD) prototype showing the inflated large air bellow on the right side, the inflated small air bellow on the left side, and a body lying on the mattress in a 30° lateral tilt position.

Statistical analysis

Demographic data were reported as mean and standard deviation (SD) as well as maximum and minimum. Wilcoxon signed rank test or the paired-T test was used to compare the mean peak pressure and the mean PPIs at the bony prominences between the supine and the 30° lateral tilt positions.

3. Results

There were 20 volunteers, 9 males and 11 females, recruited into this study. Demographic data of the volunteers are shown in Table 1. In the 30° lateral tilt position, the peak pressure over the occiput and the sacrococcygeal area significantly decreased but increased over the scapula and the greater trochanter with the mean peak pressure (SD) of 29.93 (3.04) and 30.29 (3.30) mmHg respectively. Figure 2 shows a shifting of the IP from the sacrococcygeal area to the left greater trochanter, the scapula and the arm. However, the PPIs decreased significantly in all bony prominences except over the greater trochanter with mean PPI (SD) of 27.65 (3.67) mmHg/cm^2 (see Table 2).

Table 1 Demographic data of 20 normal volunteers

	Min	Max	Mean	SD
Age (year)	24.00	55.00	36.00	10.68
Weight (kg)	43.00	98.00	64.27	15.05
Height (m)	1.48	1.75	1.61	0.007
BMI (kg/m^2)	18.36	39.26	24.55	5.26

Table 2 Comparison of peak pressure and peak pressure index (PPI) over bony prominences between supine and a 30° lateral tilt position

	Peak pressure *(mmHg)*			PPI *(mmHg/cm^2)*		
	Supine	Lateral tilt	p-value	Supine	Lateral tilt	p-value
Occiput	30.75 (5.37)	27.26 (5.37)	0.003	21.53 (2.89)	14.93 (4.38)	< 0.001
Spine of scapula	27.05 (4.17)	29.93 (3.04)	0.001	21.65 (4.20)	18.78 (5.21)	0.011
Sacrococcyx	35.99 (5.40)	27.26 (5.40)	< 0.001	33.76 (4.37)	27.53 (4.18)	0.001
Greater trochanter	0.00 (0.00)	30.29 (3.30)	< 0.001	0.000 (0.00)	27.65 (3.67)	< 0.001

Mean (SD); Wilcoxon signed rank test for statistical analysis

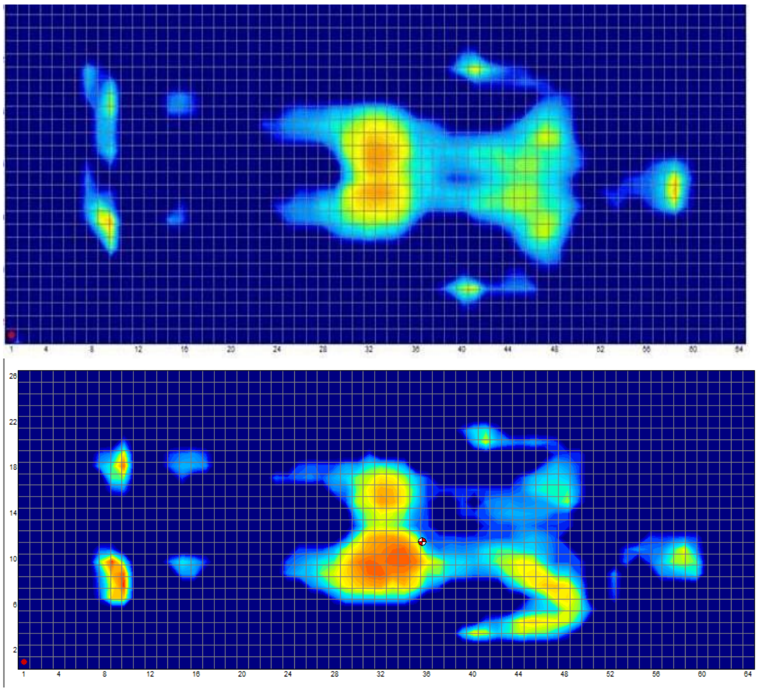

Figure 2 Pressure mapping of the whole body in bed: top – in a supine position and below – a 30° lateral tilt position with the automatic mattress turning device.

4. Discussion

This study showed us that when using the prototype of our AMTD to assist turning an individual lying in a hospital bed, pressure shifted from the sacrococcygeal area in the supine position to the greater trochanter in the 30° lateral tilt position and the peak IP over the sacrum and the greater trochanter are nearly the same as the mean IP reported in other study [15]. The latter position significantly decreased the peak pressure at the occiput (from 30.75 to 27.26 mmHg, $p = 0.003$) and the sacrococcygeal area (from 35.99 to 27.26 mmHg, $p < 0.001$) as a load of the body shifted towards the lateral side i.e., the scapula and the greater trochanter [15 & 16]. To be noted, when calculating the PPIs over all bony prominences, the 30° lateral tilt position increased the PPI only over the greater trochanter, not the scapula. On the contrary, the PPI over the scapula significantly decreased from 21.65 to 18.78 mmHg/cm^2 ($p = 0.001$) which might be due to lesser IP surrounding the peak pressure point over the spine of the scapula and some pressure was distributed to the left arm (see Figure 1). And, the PPI is the sum of IP divided by area of 9 cm^2 making the PPI lesser than the peak pressure over the scapula.

Generally the aim of turning and repositioning in bed is to reduce the IP at bony prominence so that it is as low as possible or below capillary pressure to prevent ischemia. According to previous studies, capillary pressure varies, generally ranges from 10.5 to 22.5 mmHg [17 & 18] and mean capillary pressure around the finger loop falls from 37.7 mmHg in arteriolar limb to 19.4 mmHg in apex to 14.6 mmHg in venular limb at skin temperatures of 18.7–33.1°C [19]. Moreover, the average arteriolar end of the cutaneous capillary loop blood pressure is about 32 mgHg and hence an external pressure greater than 32 mmHg is thought to occlude blood flow [17]. Therefore, the peak pressure about 30 mmHg over the greater trochanter and the scapula in the 30° lateral tilt position in our study should be acceptable.

Like other automatic turning devices, this AMTD reduces the workload on nurse as it functions automatically [9, 20]. According to a study on bio-mechanic, manual turning and repositioning of a patient in a hospital bed produces a high load on the spine [12]. Therefore, if it is replaced with this AMTD, the incidence of low back pain in nurses will decrease. However, they should be reminded that skin check is still necessary and should be done after every turn and repositioning especially in patients with physical impairments such as joint deformity, increase in muscle tones as they need an additional repositioning done manually [5]. In addition, apart from assisting mattress turning, one different feature of our AMTD from other [21] is a lateral small air bellow, when inflated, supporting and preventing a body from sliding down and reducing shearing during turning which is one of the main mechanisms of pressure injuries.

Although this AMTD has some advantages mentioned-above, it does not assure that pressure injury will not occur if used in patients with neurological deficit or mobility limitation. Tissue oxygenation was not measured and the measurement of IP was done 5 minutes after repositioning. According to the NPUAP recommendation, repositioning should be done every 2 hours [5] and hence IP measurement after a longer period may give insight into temporal changes of IP over bony prominences. In addition, as a pilot study, a small sample size of volunteers with normal body mass index was recruited. Therefore, those with underweight as well as those with neurological deficit who are at risk of pressure injury [4] should be recruited and studied in the future. Moreover, one may question whether this device works with other types of hospital mattress. Another study of us did prove its efficiency in lifting various types of hospital mattress but a heavy mattress could limit its efficiency [22].

5. Conclusion

By lifting one side of a mattress up to 30°, this new automatic mattress turning device prototype significantly reduces interface pressure over the occiput and the sacrococcyx of normal volunteers. An increase in peak pressure over the greater trochanter about 30 mmHg could be considered as acceptable. In addition, a small air bellow has an important role in preventing a body from sliding down the tilted mattress toward the lower lying side, and thus minimizing sharing force.

6. Acknowledgement

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