Journal of Tissue Viability 28 (2019) 81–86

Contents lists available at ScienceDirect

Journal of Tissue Viability

journal homepage: www.elsevier.com/locate/jtv

The effectiveness of curvilinear supine position on the incidence of pressure injuries and interface pressure among surgical patients

Yue Guo[1], Kuaile Zhao[1], Tiyu Zhao*, Yan Li, Yunhong Yu, Wan Kuang

TongJi Hospital, TongJi Medical College, Huazhong University of Science and Technology, China

A B S T R A C T

Background: Intraoperative pressure injury is still a major problem of perioperative nursing. Reducing the peak interface pressure is a valid clinical intervention for reducing the incidence of intraoperative pressure injuries. However, studies of repositioning and pressure-redistributing for surgical patients are still lacking. In this context we aimed to evaluate the effect of a curvilinear supine position on incidence of pressure injury with surgical patients in a hospital setting.

Methods: This was a prospective, randomized, controlled study, carried out from May to December 2016, included 104 surgical patients from a university hospital in China (experimental group, n = 52; control group, n = 52). Incidence of pressure injury, interface pressure, comfort and satisfaction scores from surgeons, anesthesiologists, OR nurses were recorded. Mann–Whitney U Chi-square test was used for difference of pressure injury's incidence and mixed linear model was used for interface pressure.

Results: Overall the intervention group had significant fewer intraoperative pressure injuries than the control group (0 patients [0%] vs. 9 patients [17.65%], $p = 0.002$). Compared with control group, the experimental group had significantly lower interface pressures in the sacrum and heel regions ($F = 23.81$, $p < 0.001$; $F = 60.71$, $p < 0.001$). The subjects felt comfortable in two groups were 40(80%) vs. 3(5.88%) (experimental group vs. control group), respectively ($p < 0.001$).

Conclusions: Curvilinear supine position could significantly decrease the incidence of perioperative pressure injuries in surgical patients with surgery duration more than three hours. Considering these results, we recommend that curvilinear supine position use as effective interventions to inform perioperative care delivery, reducing perioperative pressure injuries. These findings may serve to guide the application of pressure redistribution in the surgical positioning of patients during prolonged surgery.

1. Introduction

Perioperative pressure injuries (PIs, previously known as pressure ulcers) [1] are a safety concern and key quality indicators for patients, health care facilities, and medical institutions. For patients undergoing long-term surgery, the prevention of perioperative PIs remains a formidable clinical challenge [2]. Studies report that pressure injuries occur in 69% of inpatients who have undergone a surgical procedure while hospitalized [3]. PIs are localized injuries to the skin and underlying tissue that typically occur over a bony prominence as a result of external pressure, either alone or in combination with shear forces and friction. Many intrinsic and extrinsic risk factors contribute to the development of perioperative PIs in patients who have undergone surgical procedures [2,4], such as an extended surgical procedure length and a higher peak interface pressure. Some studies have shown that 8.5% of all patients undergoing surgery with a duration > 3 h developed PIs [5]. Tschannen and Hayes [6,7]reported that surgical procedures lasting more than 3 h are associated with a higher risk of perioperative PIs and that the risk increases with time [6]. Therefore, the prevention of perioperative PIs is a high priority in every healthcare facility and department. Previous studies have reported on prevention strategies such as risk assessment [8], improved support surfaces [9], and interface pressure redistribution [10,11]. However, the effects of these measures do not always meet expectations, and the prevalence of perioperative PIs remains high. This may be due to the uneven distribution of body weight in terms of body contact with the operating table, differing according to the varying sizes of each patient, and resulting in diverse pressures over the interface area between the body and the operating table, further increasing the risk of tissue damage. Pressure relief is the most important factor in the prevention of PIs. Pressure injuries "can develop" if patients experience a high amount of pressure for a very short time, or a low amount of pressure for a longer time [2,12,13]. High risk areas, such as bony prominences, are vulnerable to injury because of higher external pressure, and reducing the interface pressure between the patient's body and the support surface is a valid clinical intervention for reducing the risk of developing PIs. However, studies concerning repositioning and pressure redistribution for surgical patients remain scarce [2,14]and few studies provide data

* Corresponding author. TongJi Hospital, TongJi Medical College, Huazhong University of Science and Technology, No.1095 Jiefang Avenue, Wuhan, China.
E-mail addresses: guoyue200698@163.com (Y. Guo), 1724870542@qq.com (K. Zhao), moonbay0608@163.com (T. Zhao), 251115990@qq.com (Y. Li), yyh11252012@126.com (Y. Yu), kuangwan1@126.com (W. Kuang).

[1] Yue Guo and Kuaile Zhao contributed equally to this work.

https://doi.org/10.1016/j.jtv.2019.02.005
Received 6 September 2018; Received in revised form 18 January 2019; Accepted 19 February 2019

that fully describe the tissue interface pressures over time or the effects of long-term pressure on skin integrity in surgical patients in a supine position [7,15,16]. Based on the theory of pressure redistribution and body contours, we hypothesize that an ameliorative curvilinear supine position for surgical patients is better to redistribute interface pressure through increasing contact areas than traditional supine position. Ameliorative curvilinear supine position [17], which means the back be raised to 12° (95%CI: 11.58–12.37°), the seat plate be raised to 13° (95%CI: 12.28–13.37°), and the leg plate is lowered to 10.20° (95%CI: 10.14–11.38°). Previously, we used the Xsensor X3 pressure mapping system to measure the interface pressure in PI risk regions to confirm that the ameliorative curvilinear supine position could decrease the peak interface pressures to risk regions in healthy volunteers [17].

This study aimed to identify the effects of an ameliorative curvilinear supine position on the prevention of perioperative PIs (1–4) in surgical patients with surgery duration more than 3 h in a hospital setting.

2. Materials and methods

2.1. Study design

We performed a single-center, prospective randomized controlled trial at a general teaching hospital with 91 operating rooms, from May to December, in 2016.

2.2. Sample size

For a study of surgical positioning of a patient, limited data are available for calculating a formal sample size due to the specificity of this research area. We used the calculation in the results of our previous study of healthy volunteers to determine the standard deviation (Peak interface pressure; Mean, 53.51; SD, 15.9) [17]by PASS (version 11.0). Given a power of 80% and a 5% level of significance, a sample size of 45 participants per group was required. To allow for a drop-out rate of < 15% (with reasons for dropping out), a total sample of 104 participants was deemed necessary for recruitment.

2.3. Participants

Patients who meet the following requirements be recruited: participants > 18 years, undergoing general anesthesia and open surgery while in the supine position, expected operating time ≥3 h, expected ward/hospital stay ≥3 days, and a good understanding of written and spoken Chinese. The exclusion criteria included: a history of past or present pressure injuries (1–4), skin disease, paralysis, peripheral vascular disease, and joint dysfunction.

Three patients were excluded for different reasons. A total of 101 patients were randomized and participated in the data collection (intervention group, n = 50; control group, n = 51), and the drop-out rate was 2.88%. Patient enrolment and allocation flow through the trial is presented according to the CONSORT protocol (Fig. 1).

2.4. Randomization and blinding

A randomization and concealed allocation procedure were used to assign participants to the experimental and the control groups after obtaining informed consent. The randomization of the participants was generated using SPSS (Version 22.0) to randomly ordered blocks by an independent researcher not involved in study recruitment or intervention. Randomization codes were then placed in sequentially numbered opaque envelopes and sealed by the researcher. The allocation was conducted by another researcher, who published the randomization code after each participant opened the sealed envelope. However, blinding the participants to the group allocation was not possible due to the nature of the surgical position intervention.

2.5. Instruments and measurements

The primary outcome variable was a perioperative stage 1–4 pressure injury, deep tissue injury, or an unstageable injury, according to the National Pressure Ulcer Advisory Panel staging criteria [1]. Documentation and staging of pressure injuries was performed by the clinical team independent to this study. Operating room nurse routinely perform a head-to-toe skin assessment for each patient after the surgery. A skin check was performed between 0- and 2-days post-surgery by nursing staff in the ward, every shift. Any remarkable findings are documented, and a daily report is generated for assessment within 12 h by an independent Certified Wound Nurse. This person was independent of the study and blinded to group allocation. The prevalence of PI was calculated by total number of new and old cases/total number of the patients are included in this study. The secondary outcome variable was a peak interface pressure of five risk body parts in the supine position (that is, the occiput, scapula, sacrum, calf, and heel regions) [18], which were measured and recorded per hour once the operation began. The instrument used for measuring the interface pressure was the Xsensor X3 pressure mapping system (Xsensor Technology Corporation, Albert, Canada). This validated and reliable measures interface pressure [19]. The tertiary outcomes were the participants' comfort score and the surgeon's satisfaction score, which were recorded the immediate postoperative period and in day 1 post-surgery. These were assessed using a single-item question with a 5-point Likert scale, ranging from 1 (completely uncomfortable/dissatisfaction) to 5 (completely comfortable/satisfaction), and a score of either 4 or 5 was considered as indicating comfortable/satisfaction.

2.6. Intervention

All participants were required to wear hospital scrubs. The pressure-sensing pad was placed on the operating table under an operating sheet. The two groups of participants were requested to lie supine on the operating bed (MAQUET, Rastatt, Germany). First, a researcher recorded the participant's demographic and clinical characteristics. Second, the participant lay supine on the operating bed for 3 min to ensure the pressures and contact areas remained stable. When the participant appeared calm and comfortable, baseline measurements were recorded. Following this, participants in each of the two groups were placed in either a supine position or a curvilinear supine position. The participants in the two groups were provided with our standardized, preventive pressure injury interventions, including risk assessment for all surgical patients, skin assessment, occipital repositioning when possible and able, a check to eliminate any wrinkles in the sheets underneath the patient et al. The placement process of position was done as follows:

2.6.1. Supine position

Participants in the control group continued to lie on the surgical table in a supine position as follows: the participant lay on his back looked upward, with the trunk and upper body in line with the hips; 2) the legs were placed in a parallel position in line with the upper body; 3) both ankles were positioned in a neutral ankle joint position and supported with pillows, and the arms were placed at the sides in a neutral position or positioned on padded arm boards with the palmar surface facing down and shoulder joint at a < 90° angle.

2.6.2. Curvilinear supine position

Participants in the intervention group continued lying on the surgical table and then were placed in curvilinear supine position according to the following steps: 1) a researcher adjusted different parts of the surgical table to help maximize and match the physical curves of the participants, based on the theory of pressure redistribution and body contours for a curvilinear supine position. Generally, the head, back and seat plates of the operating table were elevated approximately to

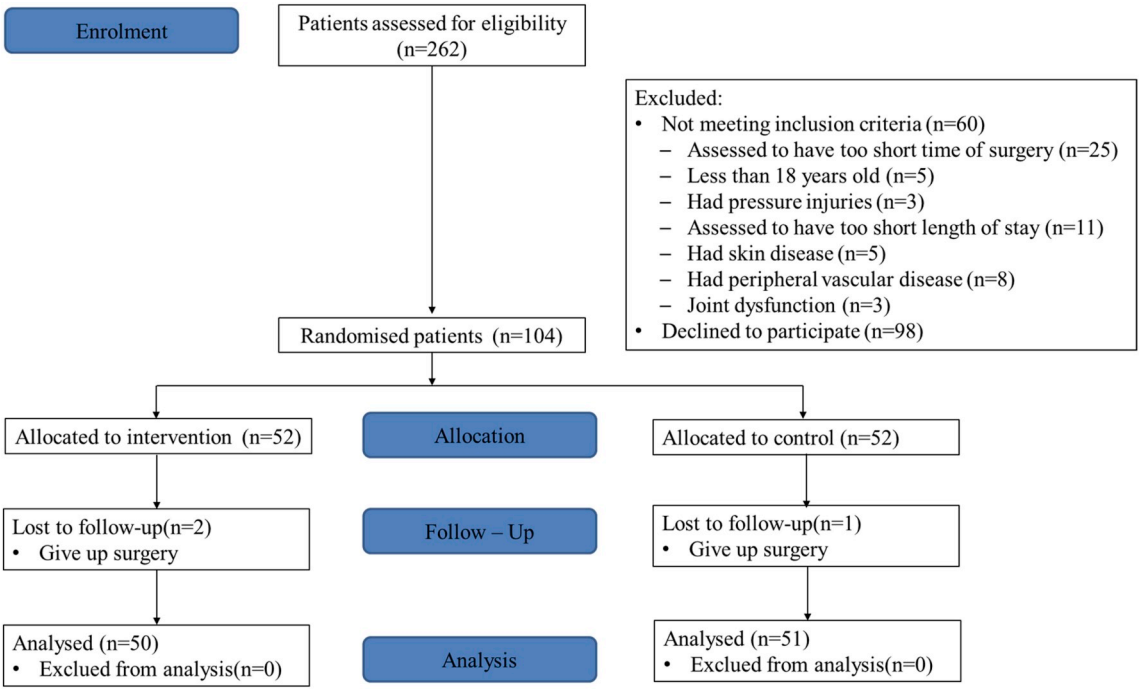

Fig. 1. Consort diagram of participant flow.

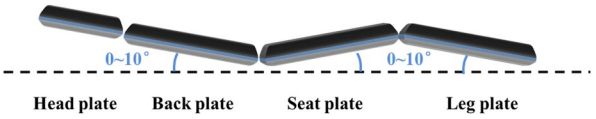

Fig. 2. Diagram of Curvilinear supine position.

10° and the leg plate was lowered to 10° (Fig. 2). Simultaneously, the researcher ensured the participants' body x-axis retained a straight position and parts of the patients' body avoided vacant spacing. However, for each participant, the degree of elevation and lowering of the table plates was influenced according to real-time data derived from a continuous bedside pressure mapping system that displayed the patient's pressure points in real-time color imagery and showed how the pressure was being distributed at the body–mat interface.

2.7. Statistical analyses

The collected data were processed using Microsoft Office Excel 2010, and statistical analyses were processed using SAS (Version 9.4). The participant demographic and clinical characteristics were analyzed using descriptive statistics. Mann–Whitney U Chi-square test was used for categorical variables and an independent *t*-test was used for continuous variables to verify homogeneity between the groups. The data regarding interface pressure for repeated measurements were deemed to be in violation of the assumption of normal distributions. Therefore, the differences in effects on the outcomes between the groups were analyzed using mixed linear models. A constrained maximum likelihood estimation algorithm in the mixed model was utilized to compare and determine the optimal fit of the data, and a type III sum of squares was used to test the hypothesis. The significance level of data was set at 0.05 with two-tailed tests.

3. Results

3.1. Participant characteristics

The participants' general demographic data and clinical characteristics are presented in Table 1. The average age of participants was 52.17 years (SD, 13.80 years; range, 20–79 years). There was no statistically significant difference between the two groups.

3.2. Patients with PIs in experimental and control groups

The prevalence of perioperative PIs (1–2) in the experimental group was 0 (day 1), 0 (day 2) and 0 (day 3). The control group had a significantly higher prevalence of PIs ($p < 0.05$). Corresponding data for the control group were 17.65%, 7.84%, and 1.96% (Table 2). Table 2 shows the movement of patients between PI categories during the days of follow-up. The most common PI locations were heels (category 1, n = 6; category 2, n = 1), sacrum (category 1, n = 1), and scapula (category 1, n = 1).

3.3. Interface pressures in five areas in the two groups over time

The overall interface pressure of the five risk areas for the two groups is shown in Fig. 3. Compared with the control group, the experimental group had significantly lower interface pressures in the sacrum and heel regions. For more accurate statistical results, we included six time nodes for the repeated-measures mixed linear model statistics. The results showed that there were statistically significant changes in interface pressures to the sacrum and heel regions over all 5-h periods ($p < 0.001$). In the experimental group, the interface pressure of the sacrum and heel regions reduced rapidly after placing the participants in position, and then increased gradually within 5 h and then later stabilized. Similarly, the figures in the control group continued increasing overtime, and were significantly higher than the experimental group ($p < 0.05$).

3.4. Patients' comfort and surgeons' satisfaction

The subjects felt comfortable in two groups were 40(80%) vs. 3(5.88%) (experimental group vs. control group), respectively ($p < 0.001$). The surgeons' satisfaction rates in the experimental and control groups were 100% and 98.04%, and the difference was not statistically significant ($p > 0.05$) (See Table 3).

Table 1
Homogeneity tests for general demographic and clinical characteristics at baseline.

Variables	Curvilinear supine position group (n = 50,%)	Supine position group(n = 51, %)	$\chi 2/Z$	*P*
Age(year)			−1.740	0.082
18–40	13(26)	7(13.7)		
40–65	31(62)	31(60.8)		
66–79	6(12)	13(25.5)		
Sex			0.378	0.539
Male	38(76)	36(70.6)		
Female	12(24)	15(29.4)		
Education level			2.433	0.296
Below high school	30(60)	34(66.7)		
High school	15(30)	9(17.6)		
College and higher	5(10)	8(15.7)		
Smoking			0.013	0.908
Yes	21(42)	22(43.1)		
No	29(58)	29(56.9)		
Drinking			0.003	0.958
Yes	11(22)	11(21.6)		
No	39(78)	40(78.4)		
BMI			−0.408	0.684
15.55–18.5	6(12)	5(9.8)		
18.5–25.0	34(68)	38(74.5)		
25.0–31.24	10(20)	8(15.7)		
Complications			0.890	0.641
None	37(74)	40(78.4)		
Hypertension	8(16)	5(9.8)		
Diabetes	5(10)	6(11.8)		
Serum albumin(g/L)			2.774	0.096
30.9–35.0	7(14)	14(27.5)		
35.0–46.4	43(86)	37(72.5)		
Hemoglobin(g/L)			−1.233	0.217
60–90	2(4)	4(7.8)		
90–110	5(10)	8(15.7)		
110–160	43(86)	39(76.5)		
Intraoperative blood transfusion(mL)			−0.122	0.903
0	35(70)	36(70.6)		
0–800	7(14)	10(19.6)		
800–2200	8(16)	5(9.8)		
Operation time(hour)			−0.092	0.927
3-4	25(50)	24(47.1)		
4-6	13(26)	12(23.5)		
> 6	12(24)	15(29.4)		
Surgery			−0.701	0.483
Hepatectomy	31 (62)	35 (68.6)		
Pancreatectomy	8 (16)	7 (13.7)		
Radical laryngectomy	11 (22)	9 (17.6)		

4. Discussion

Repositioning techniques known as “weight shifts” are used to redistribute pressure from one area to another to restore blood flow to the tissue [20]. Pressure redistribution is a common, inexpensive, and effective method recommended by healthcare professionals to reduce peak interface pressures and increase the duration of tissue resistance to vulnerable tissues [12,21]. Our findings demonstrated that a curvilinear spine position achieved greater pressure redistribution versus the traditional supine positioning on the operating table. Compared to a traditional supine position, the curvilinear supine position group had a significantly lower prevalence of PIs (ratio, 0 vs 17.65%; p = 0.002). We consider that this decrease is likely to be as a result of the lower peak interface pressures across the risk regions, increasing the duration of vulnerable tissue resistance. While interface pressures were significantly increased at the calf muscle, we assert this increase is a result of pressure redistribution achieved by curvilinear supine position protecting more vulnerable areas of the body (heels and sacrum) without causing harm to this comparatively large muscle group (such as calf) in the lower extremity. Our assumption is supported by Reswick [21]who showed that muscle could bear loads of approximately 50 mmHg for 6 h. Our findings are consistent with international guideline recommendations that suggest pressure relief and redistribution are beneficial for preventing pressure injuries for many sub-groups of patients deemed to be at high risk of developing PIs [1]. Lippoldt and colleagues [11] conducted a similar study and combined a 20° head-of-bed elevation with a 10° reverse Trendelenburg position to achieve significantly lower interface pressures. However, they did not explore the effects of this position regarding the prevalence of PIs in clinical practice.

Positioning devices are often used to facilitate repositioning in perioperative care. Many researchers have studied the effects of various positioning devices to prevent PIs; however, their findings have differed [22–24]. Although various positioning devices offer differing features and benefits, no one positioning device is likely to be effective for all patients [25]. In a traditional supine position, pillows are typically propped behind the patient to help maintain position and support bony prominences such as the heels and knees. However, pillows come in multiple sizes, shapes, and densities, with various moisture-proof coverings. With repeated use, pillows become flatter and less supportive [25]. Inappropriate use of the positioning devices could increase the risk of PIs. Studies have shown that some pressure-redistribution overlays significantly decrease the postoperative prevalence of PIs in surgical patients [26]. Al-Majid et al. found that heel offloading significantly increased sacral pressure [27]. Our findings suggest that elevating the back and seat plates of the operating table, combined with a lowered leg plate could redistribute pressure from the heel and sacrum regions to the calf region, significantly decreasing the pressure interface over the heels and sacrum without any additional supporting devices, while maintaining the knee in a relaxed state, and decreasing the prevalence of PIs.

Healthy capillary pressure ranges from 20 mmHg to 40 mmHg, with 32 mmHg considered the average pressure. Mizuno has proposed that interface pressure to be kept below 32 mmHg and as low as possible [28]. While, Peterson et al. [24] showed that peak interface pressure

Table 2
Patients with PIs in the intervention and control groups.

	Day1(the immediate postoperative period)		Day 2		Day 3	
	Intervention	Control	Intervention	Control	Intervention	Control
	N = 50	N = 51	N = 50	N = 51	N = 50	N = 51
	N(%)	N(%)	N(%)	N(%)	N(%)	N(%)
No PI	50(100%)	42(82.35%)	50(100%)	47(92.16%)	50(100%)	50(98.04%)
PI1	0(0)	8(15.69%)	0(0)	3(5.88%)	0(0)	0(0)
PI2	0(0)	1(1.96%)	0(0)	1(1.96%)	0(0)	1(1.96%)
Z	−3.096		−2.010		−0.990	
P	0.002		0.044		0.322	

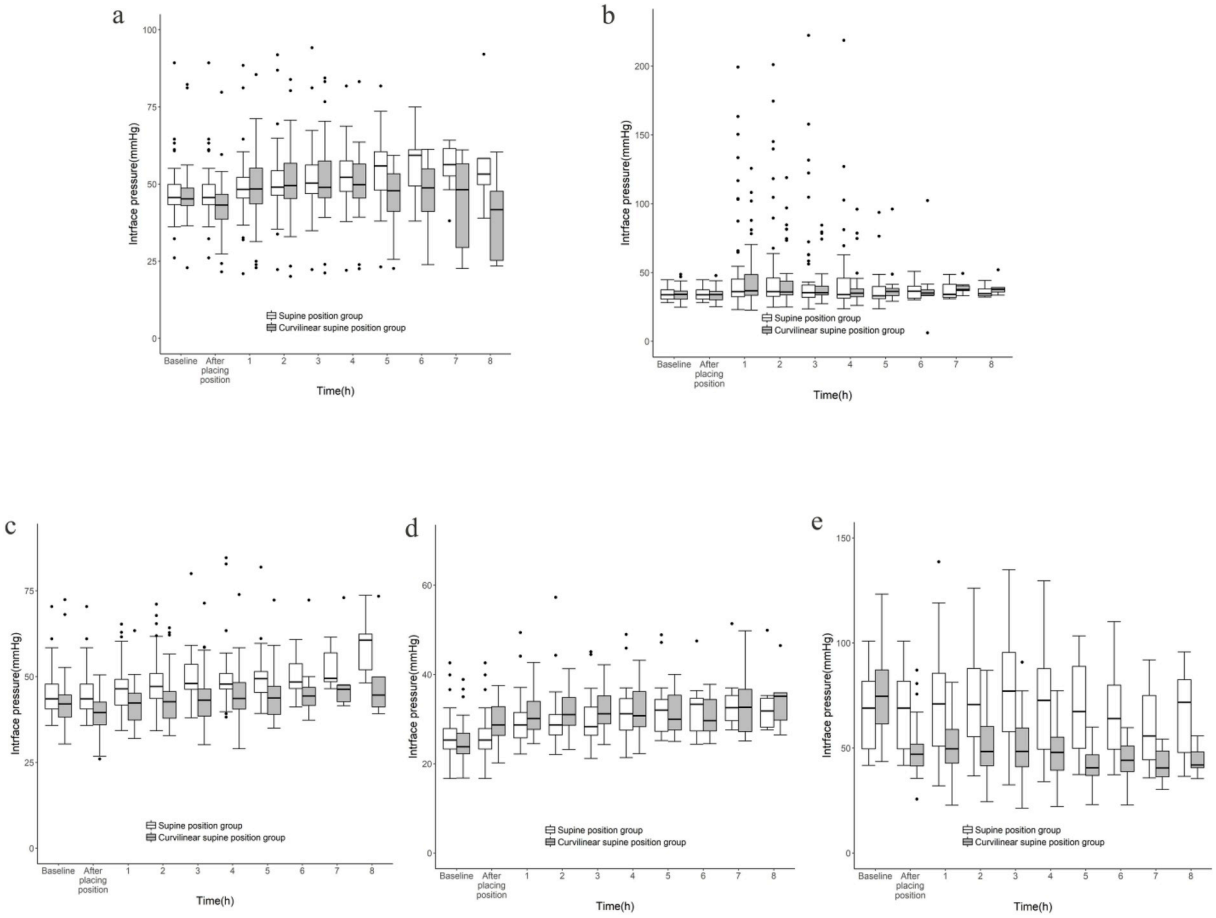

Fig. 3. Peak interface pressure over time in both groups at (a) occiput, (b) scapula, (c) sacrum, (d) calf, and (e) heel. Time 0 means the baseline peak interface pressure.

Table 3
Comparison of satisfaction scores for surgeons, anesthesiologists, and OR nurses.

Groups	N	Satisfaction n (%)		
		Surgeon	Anesthetist	OR nurse
Intervention	50	50(100%)	50(100%)	50(100%)
Control	51	50(98.04%)	51(100%)	51(100%)
χ^2		1.376	–	–
P		0.241	–	–

over the sacrum reached a high of almost 50 mmHg in the supine position, which was significantly more than the recommended average of32 mmHg, consistent with our findings. However, no pressure injuries occurred in our curvilinear supine position group during the observation period. Research is lacking on the relationship between the peak interface pressure and capillary pressure, and further study is needed.

Our study revealed that the pressure at the monitoring site increased with the operation time in participants under general anesthesia in the traditional supine position group. The interface pressure in the control group continued to increase. Simultaneously, interface pressure in the curvilinear supine position increased within 4 h of the operation. The interface pressures over the sacrum and heel regions maintained a significantly lower level than that of the control group. However, the interface pressure increased at first and then tended to stabilize or decrease after the operation time reached 5 h in the intervention group (Fig. 3.). This change may be due to shear force or the nature of the operation, but we were unable to obtain clear evidence on correlations between interface pressures and shear forces.

4.1. Limitations

This study has some limitations. Firstly, this study was conducted in one public hospital in China. Further research could investigate these issues in hospitals with different ownerships in China health system. Second, the shearing forces in this study cannot be measured (by using interface pressure mapping) and a follow-up of 2 days may be too short to identify the development of severe PI. In addition, the number of samples in the study for more than 6 h was small that the study failed to clarify the relationship between interface pressure, operation time and surgical position. In future, we should measure interface pressure in participants over a long period. Furthermore, as the future research going on, we can obtain relevant data on the correlations between skin perfusion pressure, capillary pressure and the peak interface pressure during the surgery measured by using moorVMS-PRES pressure module and Xsensor X3 pressure mapping system.

5. Conclusions

This study used a prospective, randomized controlled design to evaluate the effects of a curvilinear supine position on the prevalence of PIs. The present findings indicated that a curvilinear supine position could significantly decrease the prevalence of perioperative PIs in surgical patients with a surgery duration of > 3 h. We found that the interface pressures were associated with a significantly increased operation time over high-risk areas for perioperative PIs in the control group, whereas the interface pressures over the sacrum and heel regions in the

curvilinear supine position group were significantly lower than those of the control group during the whole operation. Finally, these findings may serve to guide the application of pressure redistribution in the surgical positioning of patients during prolonged surgery.

Ethical considerations

All patients received oral and written information about the study and were told that participation was voluntarily, confidentiality was assured, and they could withdraw at any time without explanation. Signed, informed consent was obtained from the patients or from a family member if a patient was unable to sign. The healthcare workers included in the study also received oral and written information about this study. The ethical approval of this study was obtained from the institutional review board of the study hospital's human research ethics committee (IRB ID:TJ-C20160102). Also, this study was registered in the clinical trial register of Chinese Clinical Trial Registry. (Registration number was ChiCTR-IOR-16009061).

Declarations of interest

None.

Funding

This study was supported by the Natural Science Foundation of Hubei Provence of China (grant number 2012FFB02511).

References

[1] NPUAP. National Pressure Ulcer Advisory Panel (NPUAP) announces a change in terminology from pressure ulcer to pressure injury and updates the stages of pressure injury. http://www.npuap.org/national-pressure-ulcer-advisory-panel-npuap-announces-a-change-in-terminology-from-pressure-ulcer-to-pressure-injury-and-updates-the-stages-of-pressure-injury/April 13, 2016.

[2] Spruce L. Back to basics: preventing perioperative pressure injuries. AORN J 2017;105:92–9. 105:92-9. 92-99. 10.1016/j.aorn.2016.10.018.

[3] Meehan AJ, Beinlich NR, Hammonds TL. A nurse-initiated perioperative pressure injury risk assessment and prevention protocol. AORN J 2016;104:554–65.

[4] Malkoun M, Huber J, Huber D. A comparative assessment of interface pressures generated by four surgical theatre heel pressure ulcer prophylactics. Int Wound J 2012;9:259–63. https://doi.org/10.1111/j.1742-481X.2011.00865.x.

[5] Allegretti AL, Malkiewicz A, Brienza DM. Measuring interface pressure and temperature in the operating room. Adv Skin Wound Care 2012;25:226–30. https://doi.org/10.1097/01.ASW.0000414706.33267.db.

[6] Tschannen D, Bates O, Talsma A, Guo Y. Patient-specific and surgical characteristics in the development of pressure ulcers. Am J Crit Care: An Official Publication, American Association of Critical-Care Nurses 2012;21:116–25. https://doi.org/10.4037/ajcc2012716.

[7] Hayes RM, Spear ME, Lee SI, Krauser Lupear BE, Benoit RA, Valerio R, et al. Relationship between time in the operating room and incident pressure ulcers: a matched case-control study. Am J Med Qual: The Official Journal of the American College of Medical Quality 2015;30:591–7. https://doi.org/10.1177/1062860614545125.

[8] Munro CA. The development of a pressure ulcer risk-assessment scale for perioperative patients. AORN J 2010;92:272–87. https://doi.org/10.1016/j.aorn.2009.09.035.

[9] Kirkland-Walsh H, Teleten O, Wilson M, Raingruber B. Pressure mapping comparison of four OR surfaces. AORN J 2015;102:61.e1–9. https://doi.org/10.1016/j.aorn.2015.05.012.

[10] Anderson R, Kleiber C, Greiner J, Comried L, Zimmerman M. Interface pressure redistribution on skin during continuous lateral rotation therapy: a feasibility study. Heart Lung : J Crit Care 2016;45:237–43. https://doi.org/10.1016/j.hrtlng.2016.02.003.

[11] Lippoldt J, Pernicka E, Staudinger T. Interface pressure at different degrees of backrest elevation with various types of pressure-redistribution surfaces. Am J Crit Care: An Official Publication, American Association of Critical-Care Nurses 2014;23:119–26. https://doi.org/10.4037/ajcc2014670.

[12] Gefen A. Reswick and Rogers pressure-time curve for pressure ulcer risk. Part 2. Nurs Stand 2009;23:40–4. https://doi.org/10.7748/ns2009.07.23.46.40.c7169.

[13] Mower J. Berry and Kohn's operating room technique. AORN J 2013;97:155–6. 12th Edition.

[14] Pickham D, Berte N, Pihulic M, Valdez A, Mayer B, Desai M. Effect of a wearable patient sensor on care delivery for preventing pressure injuries in acutely ill adults: a pragmatic randomized clinical trial (LS-HAPI study). Int J Nurs Stud 2018;80:12–9https://doi.org/10.1016/j.ijnurstu.2017.12.012.

[15] Defloor T. The effect of position and mattress on interface pressure. Appl Nurs Res : ANR. 2000;13:2–11.

[16] Harada C, Shigematsu T, Hagisawa S. The effect of 10-degree leg elevation and 30-degree head elevation on body displacement and sacral interface pressures over a 2-hour period. J Wound, Ostomy Cont Nurs: Official Publication of The Wound, Ostomy and Continence Nurses Society/WOCN 2002;29:143–8.

[17] Guo Y, Li Y, Zhao K, Yue X, Yu Y, Kuang W, et al. Effects of curvilinear supine position on tissue interface pressure: a prospective before-and-after study. Journal of Wound Ostomy & Continence Nursing Official Publication of the Wound Ostomy & Continence Nurses Society 2017;44:450–4. https://doi.org/10.1097/WON.0000000000000360.

[18] Boyko TV, Longaker MT, Yang GP. Review of the current management of pressure ulcers. Adv Wound Care 2018;7:57–67. https://doi.org/10.1089/wound.2016.0697.

[19] Stinson M, Ferguson R, Porter-Armstrong A. Exploring repositioning movements in sitting with 'at risk' groups using accelerometry and interface pressure mapping technologies. J Tissue Viability 2018;27:10–5. https://doi.org/10.1016/j.jtv.2017.11.001.

[20] Sonenblum SE, Vonk TE, Janssen TW, Sprigle SH. Effects of wheelchair cushions and pressure relief maneuvers on ischial interface pressure and blood flow in people with spinal cord injury. Arch Phys Med Rehabil 2014;95:1350–7https://doi.org/10.1016/j.apmr.2014.01.007.

[21] Reswick JB, Rogers JE. Experience at rancho los amigos hospital with devices and techniques to prevent pressure sores. In: Kenedi RM, Cowden JM, editors. Bed sore biomechanics: proceedings of a seminar on tissue viability and clinical applications organised in association with the department of biomedical engineering, the institute of orthopaedics (university of london), royal national orthopaedic hospital, stanmore, london, and held at the university of strathclyde, glasgow, in august, 1975 London: Macmillan Education UK; 1976. p. 301–10. https://doi.org/10.1007/978-1-349-02492-6_38.

[22] Powers J. Two methods for turning and positioning and the effect on pressure ulcer development: a comparison cohort study. J Wound, Ostomy Cont Nurs: Official Publication of The Wound, Ostomy and Continence Nurses Society/WOCN 2016;43:46–50. https://doi.org/10.1097/won.0000000000000198.

[23] Clements L, Moore M, Tribble T, Blake J. Reducing skin breakdown in patients receiving extracorporeal membranous oxygenation. Nurs Clin 2014;49:61–8. https://doi.org/10.1016/j.cnur.2013.11.003.

[24] Peterson M, Schwab W, McCutcheon K, van Oostrom JH, Gravenstein N, Caruso L. Effects of elevating the head of bed on interface pressure in volunteers. Crit Care Med 2008;36:3038–42. https://doi.org/10.1097/CCM.0b013e31818b8dbd.

[25] Krapfl LA, Langin J, Pike CA, Pezzella P. Does incremental positioning (weight shifts) reduce pressure injuries in critical care patients? J Wound, Ostomy Cont Nurs: Official Publication of The Wound, Ostomy and Continence Nurses Society/WOCN 2017;44:319–23. https://doi.org/10.1097/won.0000000000000340.

[26] Pham B, Teague L, Mahoney J, Goodman L, Paulden M, Poss J, et al. Support surfaces for intraoperative prevention of pressure ulcers in patients undergoing surgery: a cost-effectiveness analysis. Surgery 2011;150:122–32. https://doi.org/10.1016/j.surg.2011.03.002.

[27] Al-Majid S, Vuncanon B, Carlson N, Rakovski C. The effect of offloading heels on sacral pressure. AORN J 2017;106:194–200https://doi.org/10.1016/j.aorn.2017.07.002.

[28] Mizuno J, Takahashi T. Evaluation of external pressure to the sacral region in the lithotomy position using the noninvasive pressure distribution measurement system. Therapeut Clin Risk Manag 2017;13:207–13. https://doi.org/10.2147/TCRM.S122489.