J. Phys. Ther. Sci. 36: 571–576, 2024

The Journal of Physical Therapy Science

Original Article

# Interventional study of comparing body pressure in different prone positions in healthy young women

Akihiro Sato, OTR[1, 2)*], Akiko Ajimi, RPT, PhD[3)], Yuko Omiya, RN, PhD[4)], Jun-Ichi Shimizu, OTR, PhD[5)]

*1) Department of Occupational Therapy, Mejiro University: 320 Ukiya, Iwatsuki-ku, Saitama-shi, Saitama 339-8501, Japan*
*2) Doctoral Program in Human Life Science, Tokyo Kasei University, Japan*
*3) Department of Physical Therapy, Mejiro University, Japan*
*4) Department of Nursing, Mejiro University, Japan*
*5) Graduate School of Human Life Science, Tokyo Kasei University, Japan*

**Abstract.** [Purpose] Although prone positioning is used to increase oxygenation in various respiratory conditions, this positioning can lead to facial and limb pressure ulcers. The aim in this study was to investigate body pressure variations in the prone position for different facial orientations and upper extremity positions. [Participants and Methods] Nineteen healthy young women participated in this study. Body pressure (maximum body pressure on the face, chest, elbows, and knees) was measured in six different prone positions with different face orientations and upper extremity positions, and the median value of each body pressure measurement was compared among postures. [Results] Face pressure tended to decrease when face orientation coincided with the raised side of the upper limb. In contrast, elbow pressure tended to be lower when the orientation of the face did not coincide with that of the raised side of the upper limb. [Conclusion] Pressure on the face and elbows can be reduced by placing the upper limbs in the prone position. This suggests that targeted and specific positioning may be useful for limiting the incidence and severity of pressure ulcers in these areas.

**Key words:** Prone positioning, Body pressure, Ulcer

*(This article was submitted May 11, 2024, and was accepted Jun. 16, 2024)*

## INTRODUCTION

Prone therapy is widely used as a noninvasive treatment for acute respiratory distress syndrome (ARDS) and coronavirus disease 2019 (COVID-19)[1–3)]. A meta-analysis of the effects of prone therapy on ARDS treatment reported improved mortality when patients were placed in the prone position for ≥12 h/day compared to <12 h/day[4)]. Furthermore, a meta-analysis of the effects of prone therapy on COVID-19 reported lower mortality and improved oxygenation when patients were placed in the prone position than in the supine position[5)]. Therefore, prone therapy is a cost-effective and beneficial modality for treating ARDS and COVID-19.

The prone position is defined by the trunk orientation and direction of gravity, and the oxygenation improvement effect depends on changes in the direction of gravity. The prone position reverses the direction of gravity, compared with the supine position, which changes the position of the heart and diaphragm, ultimately resulting in homogeneous lung perfusion and an improved V/Q ratio[6–12)]. However, complications are more common in the prone position including tube occlusion, eye and nerve damage, and pressure ulcers[13)]. In particular, facial pressure ulcers have been commonly reported, with approximately

*Corresponding author. Akihiro Sato (E-mail: a.sato@mejiro.ac.jp)

half of the patients with COVID-19 treated in the prone position having facial pressure ulcers[14]. Although device-related injury is an important factor in facial pressure ulcers in intubated patients[15], pressure control is important to prevent the risk of pressure ulcers because increased local pressure induces their development.

The relationship between trunk orientation and direction of gravity is important in prone therapy, whereas face orientation and limb position are poorly discussed owing to their non-involvement in the ventilation improvement described above, which may be related to the variability in positioning reported in prone therapy practice[16–18]. However, reducing local pressure reduces the risk of pressure ulcers during prone therapy, whereas different positioning during prone therapy may affect local pressure and increase the risk of pressure ulcers. Owing to the functional and structural connection between the head/limbs and trunk, and differences in head/limb positioning affects each other's positions through the trunk[19, 20].

This study aimed to clarify the effects of different prone positions on body pressure. Furthermore, we investigated whether placing facial pressure on where pressure ulcers are commonly reported, correlates with the range of head rotation. We believe that this study provides basic information on how to position patients in the prone position to reduce the risk of pressure ulcers.

## PARTICIPANTS AND METHODS

This interventional study compared body pressures in different prone positions in a single population[21]. In addition, the relationship between body pressure and head rotation/body mass index (BMI) were investigated. This study was approved by the Medical Ethics Review Committee of Mejiro University (approval number: 21Medical-012).

19 healthy young women were recruited using convenience sampling[22–24]. Written informed consent was obtained from the participants before the study was conducted. The inclusion criteria were as follows: (i) female sex, (ii) free from pain or other conditions that could interfere with the prone position, and (III) BMI <30. The exclusion criteria were as follows: (i) Male sex and BMI that did not meet the abovementioned criteria; and (ii) a history of orthopaedic or neurological disease that can interfere with the prone posture. Participants' mean age ± standard deviation was 19.6 ± 1.2 years and mean BMI was 21.3 ± 2.1.

Female participants were chosen because body pressure in the prone position is more likely to be affected by differences in body shape between males and females[25], and the size of the sensor sheet used to measure body pressure may not be compatible with that of males.

The participants' range of motion of head rotation was measured and they were placed in six prone positions in a random order (Fig. 1). Each position was held for 2 min on a pressure-dispersing mattress (Everfit C3, Paramount Bed Co., Tokyo, Japan), and the body pressure was recorded. Subsequently, the participants rested in a sitting position for 1 min before moving to the next test position.

The following section describes the measurement of the angle of head rotation. The basic axis of head rotation was a line connecting the right and left acromions of the scapula, whereas the moving axis was a line connecting the top of the head and the external occipital protuberance. The participants were filmed from above the head, and the angles were later calculated in 1° increments using video analysis software (Media Blend, DKH Co., Tokyo, Japan (now Q'sfix Co., Tokyo, Japan)). The automatic range of motion for each participant's head rotation was measured thrice on each side in a sitting position within a pain-free range, and the average of the three measurements on each side was used.

Body pressure was measured using the following method. A body pressure measurement sensor sheet (SR Soft Vision, Sumitomo Science & Engineering Co., Aichi, Japan) was placed on the mattress and body pressure data were extracted for 10 s, 1 min after the start of the measurement. The maximum pressure values on the face, chest, elbows, and knees were recorded from the extracted data. Two pressure sensors (SR Soft Vision full-body version and SR Soft Vision numerical version) were used simultaneously for whole-body measurements because the pressure sensor sheet (SR Soft Vision full-body version) used in this study could not measure elbow pressure (Fig. 2).

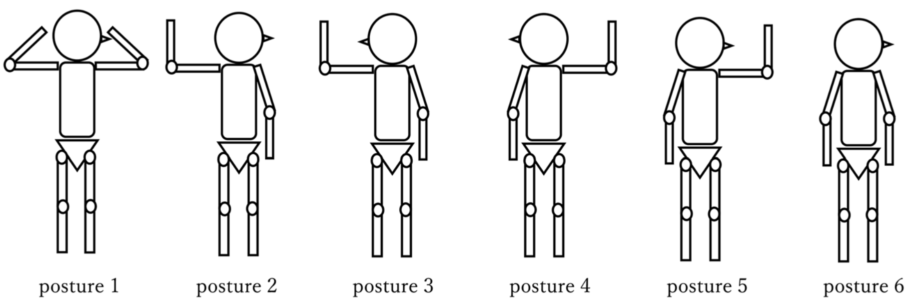


**Fig. 1.** Test postures (prone).
Participants rested for 2 min in each of six different prone postures.

The body pressure measurement sensor sheet (SR Soft Vision full-body version), used to measure body pressure on the upper body, had a pressure-sensitive area of 1,800 mm (length) × 700 mm (width), a spatial resolution of 28 $mm^2$ and a measuring range of 15–110 mmHg, with a display of 0 mmHg for <10 mmHg and 10 mmHg for between 10 mmHg and 15 mmHg. Considering the elbow, some participants had a pressure <15 mmHg, in which case the displayed value was taken as the participant's body pressure.

The body pressure measurement sensor sheet (SR Soft Vision numerical version) used for the knee had a pressure-sensitive area of 350 mm (length) × 350 mm (width), spatial resolution of 22 $mm^2$, and measurement range of 20–200 mmHg. None of the participants had body pressure <20 mmHg at the knee.

For statistical analysis, body pressure was compared using means. Analysis of variance was used to compare body pressures between test postures, and when significant differences were found, the multiple comparison method was used to confirm the differences between postures.

The range of motion of head rotation and the correlation between BMI and pressure on the face were tested using Pearson's correlation coefficient as normality was confirmed.

All tests were performed using the Windows version of R.4.2.2 (CRAN, Freeware), with significance set at <5%.

## RESULTS

Detailed body pressure data (mean ± standard deviation) for each posture in the prone position are shown in Table 1. For the elbows, data are shown only for postures in which the elbows were in contact with the mat (posture 1: both elbows; postures 2 and 3: left elbow; postures 4 and 5: right elbow).

Significant differences in body pressure based on the posture were found only for the face and left and right elbows; no significant differences were found for the chest and knees based on posture.

In the prone position wherein the direction of the face and the side of the raised upper limb were different (postures 2 and 4), the pressure of the face tended to be higher than that in other positions (posture1<4***, posture 3<4**, posture 5<4***, posture 0.3<2*).

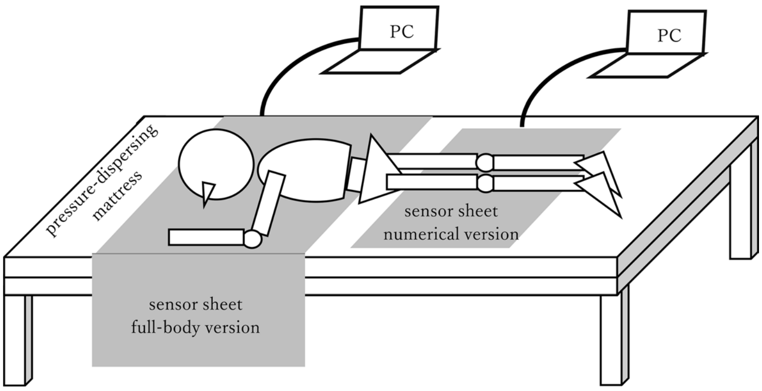


**Fig. 2.** Body pressure measurement.
A body pressure measurement sensor sheet (SR Soft Vision Sumitomo Science & Engineering Co.) was placed on the mattress. Two pressure sensors were used, because it was not possible to measure pressure at the elbow with only one sensor sheet. The maximum pressure values on the face, chest, elbows, and knees were recorded from the data obtained. PC: personal computer.

**Table 1.** Test posture and pressure in each parts of the body (mean ± standard deviation)

| | Posture 1 | Posture 2 | Posture 3 | Posture 4 | Posture 5 | Posture 6 | Significant difference |
|---|---|---|---|---|---|---|---|
| Face | 42.6 ± 5.8 | 48.4 ± 9.6 | 42.1 ± 6.9 | 51.1 ± 8.6 | 41.1 ± 6.6 | 46.0 ± 7.6 | pos.1<4***, pos.3<4**, pos.5<4***, pos.3<2* |
| Chest | 39.7 ± 4.7 | 40.6 ± 6.9 | 38.5 ± 3.0 | 39.3 ± 6.4 | 41.6 ± 5.6 | 39.5 ± 6.2 | n.s. |
| Elbow (Rt.) | 26.4 ± 7.5 | - | - | 16.7 ± 7.1 | 25.1 ± 6.3 | - | pos.4<1***, pos.4<5*** |
| Elbow (Lt.) | 26.8 ± 4.8 | 17.3 ± 6.4 | 23.8 ± 6.7 | - | - | - | pos.2<1**, pos.2<3** |
| Knee (Rt.) | 41.3 ± 11.9 | 40.1 ± 9.1 | 41.5 ± 12.7 | 41.9 ± 11.4 | 41.0 ± 7.5 | 42.8 ± 10.4 | n.s. |
| Knee (Lt.) | 44.3 ± 11.3 | 43.3 ± 8.9 | 42.7 ± 11.4 | 44.7 ± 11.5 | 45.5 ± 10.7 | 43.9 ± 14.2 | n.s. |

All units are in mmHg. *p<0.05, **p<0.01, ***p<0.001.
For the elbows, pressure was only measured in the upper limb elevation position. This was because the elbows were only in contact with the mat when the upper limb was elevated. pos: posture; Rt: right; Lt: left.

Body pressure on the elbows tended to be significantly lower in the prone position in which the direction of the face and the side of the raised upper limb were different (postures 2 and 4), than in other prone positions.

Overall, body pressure in all prone positions, except the elbow, was approximately 40 mmHg, which is considered a borderline value for risk of pressure ulcer, and only the elbow tended to have a lower pressure. The correlation coefficients between BMI and facial body pressure in each posture ranged from −0.05 to 0.44, and no significant correlation was found between BMI and facial body pressure in any posture.

The relationship between the range of motion of head rotation and body pressure on the face in each limb position was investigated. The range of head rotation (mean ± standard deviation) of the participants was 60.1° ± 9.0° for right rotation and 61.5° ± 11.1° for left rotation, with no difference between right and left. The correlation coefficients between a rotational range of motion and facial body pressure in each posture ranged from −0.41 to 0.01, and no significant correlation was found between the range of head rotation and facial body pressure in any posture.

Figure 3 shows examples of the typical distribution of upper body pressure for each examination position.

In the posture in which both upper limbs were raised (posture 1), the body pressure in the chest was approximately equally distributed between the left and right sides. In the position where the direction of the face and the side of the raised upper limb were the same (postures 3 and 5), many participants showed a bias of body pressure in the chest towards either side (posture 3: 17/19 participants; posture 5: 15/19 participants). In contrast, in the prone position, where the direction of the face and the side of the raised upper limb were different (postures 2 and 4), more participants showed an equal distribution of pressure in the thoracic region than in postures 3 and 5. In the posture with both upper limbs down (posture 6), the body pressure tended to be slightly higher on the chest on the side opposite to the direction of the face.

In positions where the direction of the face and the side of the raised upper limb were the same (postures 3 and 5), more participants tended to have body pressure distributed widely over the forearms than in the prone position where the direction of the face and the side of the raised upper limb were different (postures 2 and 4).

## DISCUSSION

This study investigated the effect of the head and upper limb positions on pressure in the prone position. The results showed that pressure on the face and elbows could be influenced by the head and upper limb positions. This study suggests that facial pressure can be reduced by elevating the upper limbs ipsilateral to the face. In addition, although elbow pressure was influenced by positioning, vertical pressure was low, suggesting that factors other than vertical pressure should be considered for prevention of pressure ulcer.

Local body pressure is an important risk factor for the development of pressure ulcers, with a cutoff value of approximately 40 mmHg. In the present study, the body pressure on the face, chest, and knees was approximately 40 mmHg, suggesting that these areas are at high risk of pressure ulcers in the prone position, which is mostly consistent with that reported by studies on actual pressure ulcer incidence[26, 27]. In contrast, the pressure at the elbow was approximately 20 mmHg, with few reports of actual pressure ulcers. Three factors can cause pressure ulcers: compressive, tensile, and shear stress[28]. The pressure sensor used in this study measured the compressive stresses of the three factors. In the prone position, compressive stresses on the elbow are relatively low; therefore, an approach that reduces tensile and shear stresses may be effective for treating elbow pressure ulcers.

The face is the most commonly reported site of pressure ulcers in the prone position. In this study, facial pressure tended to be higher when the face orientation was different from the side of the raised upper limb (postures 2 and 4). However, the

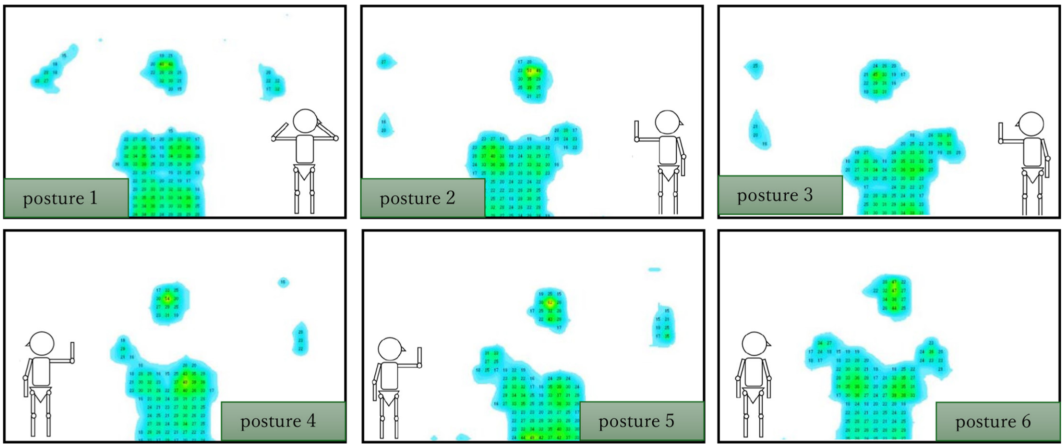


**Fig. 3.** Examples of the typical distribution of upper body pressure for each test postures.
Blue, green and yellow indicate higher body pressure in that order.

facial pressure tended to be lower when the face orientation and the side in which the upper limb was elevated were the same (postures 3 and 5). This suggests that the relationship between face orientation and the side of the raised upper limb influences the body pressure on the face.

In the prone position, the head rotation must be lateral for breathing, whereas trunk rotation supports the head rotation required for the prone position. Head rotation causes ipsilateral trunk rotation through the upright reflex. Additionally, the unilateral elevation of the upper limb in the prone position causes trunk rotation to the side of the elevated limb. In postures 2 and 4, trunk rotation was offset because the direction of trunk rotation caused by head rotation was different from that caused by upper limb elevation. This was supported by the fact that there was little imbalance in the distribution of body pressure in the chest region in postures 2 and 4, as shown in Fig. 3. When there is less trunk rotation, a greater head rotation in the prone position is required. Increased head rotation would have increased the static tension in the contralateral rotators and ligaments, which may have contributed to increased facial pressure. In contrast, in postures 3 and 5, the direction of trunk rotation caused by head rotation and elevation of the upper limbs were the same; therefore, trunk rotation was considered easier. Trunk rotation may have reduced the head rotation required for postures 3 and 5. The uneven distribution of chest pressure as shown in Fig. 3 (postures 3 and 5) may be the result of trunk rotation. In postures 3 and 5, trunk rotation supported head rotation, which may have contributed to reduced facial pressure.

Body pressure at the elbow tended to be lower in postures 2 and 4, where the orientation of the face and the raised side of the upper limb were different, and some participants did not have their elbow in contact with the mat (body pressure, 0 mmHg). Sufficient external rotation of the shoulder joint is required for the elbow to make contact with the mat. Toyoda et al. compared the range of motion of external rotation of the shoulder joint in 90° abduction and 30° horizontal flexion and reported that the range of motion of the external rotation was higher in 30° horizontal flexion[29]. In postures 3 and 5, the shoulder joint on the elevated side was slightly more horizontally flexed than that in postures 2 and 4 owing to trunk rotation. Therefore, the shoulder joints were more likely to be externally rotated and the elbows were more likely to be in contact with the mat, which may have influenced the increased pressure on the elbows. In contrast, in postures 2 and 4, it was assumed that participants without a sufficient external rotational range of motion of the shoulder had more body pressure on the hand than on the elbow.

Head rotation is necessary for breathing in the prone position. The results of this study showed no significant correlation between head rotation and body pressure on the face. The participants in this study were healthy young woman. As age and sex also influence joint flexibility[30, 31], it is speculated that the subjects had sufficient head and neck mobility to assume a prone position.

This study has three potential limitations. First, the sample size of 19 young women is insufficient and does not necessarily reflect the trends among young women. The fact that there was only one set of measuring equipment and that only one participant could perform the measurement at a time, had an impact on the recruitment of participants. Second, although we considered trunk rotation to be a factor influencing the pressure on the face and elbows, this was only inferred from the distribution of body pressure, and actual trunk rotation was not measured. This assumption should be confirmed in future studies. Third, the environment at the time of measurement did not correspond to the medical care situation because medical care involves regular changes in position, and air mats are sometimes used in addition to the mats used in this experiment. In the future, we plan to collect data on different medical environments, such as different mat types and changes in body pressure over time.

The aim of prone therapy is to improve ventilation; however, head and limb positioning are often not considered. To maximize the benefits of prone therapy, it is essential to minimize the complications, and prone management should combine easy access to medical procedures such as ventilators and intravenous fluids with a reduction in complications such as pressure ulcers. Pressure ulcers, particularly those on the face, are common complications of prone positioning and must be carefully considered during prone therapy.

This study investigated the effect of head and upper limb positions on pressure in the prone position. The results showed that pressure on the face and elbows could be influenced by the head and upper limb positions. This study suggests that facial pressure can be reduced by elevating the upper limbs ipsilateral to the face. However, for clinical reasons, it may not always be possible to elevate the ipsilateral upper limb towards the face. In such cases, caregivers must consider more frequent repositioning and utilisation of other pressure-reduction or offloading strategies. In addition, although elbow pressure was influenced by positioning, vertical pressure was low, suggesting that factors other than vertical pressure should be considered for prevention of pressure ulcers.

## *Conflict of interest*

The authors have no conflicts of interest directly relevant to the content of this article.

## REFERENCES

1) Kallet RH: A comprehensive review of prone position in ARDS. Respir Care, 2015, 60: 1660–1687. [Medline] [CrossRef]
2) Mathews KS, Soh H, Shaefi S, et al. STOP-COVID Investigators: Prone positioning and survival in mechanically ventilated patients with coronavirus disease 2019-related respiratory failure. Crit Care Med, 2021, 49: 1026–1037. [Medline] [CrossRef]
3) Zaaqoq AM, Barnett AG, Griffee MJ, et al. COVID-19 Critical Care Consortium (COVID Critical): Beneficial effect of prone positioning during venovenous extracorporeal membrane oxygenation for coronavirus disease 2019. Crit Care Med, 2022, 50: 275–285. [Medline] [CrossRef]
4) Munshi L, Del Sorbo L, Adhikari NK, et al.: Prone position for acute respiratory distress syndrome. A systematic review and meta-analysis. Ann Am Thorac Soc, 2017, 14: S280–S288. [Medline] [CrossRef]
5) Chua EX, Zahir SM, Ng KT, et al.: Effect of prone versus supine position in COVID-19 patients: a systematic review and meta-analysis. J Clin Anesth, 2021, 74: 110406 [CrossRef]. [Medline]
6) Henderson AC, Sá RC, Theilmann RJ, et al.: The gravitational distribution of ventilation-perfusion ratio is more uniform in prone than supine posture in the normal human lung. J Appl Physiol, 2013, 115: 313–324. [Medline] [CrossRef]
7) Petersson J, Rohdin M, Sánchez-Crespo A, et al.: Posture primarily affects lung tissue distribution with minor effect on blood flow and ventilation. Respir Physiol Neurobiol, 2007, 156: 293–303. [Medline] [CrossRef]
8) Musch G, Layfield JD, Harris RS, et al.: Topographical distribution of pulmonary perfusion and ventilation, assessed by PET in supine and prone humans. J Appl Physiol, 2002, 93: 1841–1851. [Medline] [CrossRef]
9) Orphanidou D, Hughes JM, Myers MJ, et al.: Tomography of regional ventilation and perfusion using krypton 81m in normal subjects and asthmatic patients. Thorax, 1986, 41: 542–551. [Medline] [CrossRef]
10) Kaneko K, Milic-Emili J, Dolovich MB, et al.: Regional distribution of ventilation and perfusion as a function of body position. J Appl Physiol, 1966, 21: 767–777. [Medline] [CrossRef]
11) Jones AT, Hansell DM, Evans TW: Pulmonary perfusion in supine and prone positions: an electron-beam computed tomography study. J Appl Physiol, 2001, 90: 1342–1348. [Medline] [CrossRef]
12) Amis TC, Jones HA, Hughes JM: Effect of posture on inter-regional distribution of pulmonary perfusion and VA/Q ratios in man. Respir Physiol, 1984, 56: 169–182. [Medline] [CrossRef]
13) Lee JM, Bae W, Lee YJ, et al.: The efficacy and safety of prone positional ventilation in acute respiratory distress syndrome: updated study-level meta-analysis of 11 randomized controlled trials. Crit Care Med, 2014, 42: 1252–1262. [Medline] [CrossRef]
14) Shearer SC, Parsa KM, Newark A, et al.: Facial pressure injuries from prone positioning in the COVID-19 era. Laryngoscope, 2021, 131: E2139–E2142. [Medline] [CrossRef]
15) Martel T, Orgill DP: Medical device-related pressure injuries during the COVID-19 pandemic. J Wound Ostomy Continence Nurs, 2020, 47: 430–434. [Medline] [CrossRef]
16) Radsel P, Gorjup V, Jazbec A, et al.: Pregnancy complicated by influenza A ARDS requiring consecutive VV-ECMO treatment with successful vaginal delivery. J Artif Organs, 2018, 21: 471–474. [Medline] [CrossRef]
17) Oliveira VM, Piekala DM, Deponti GN, et al.: Safe prone checklist: construction and implementation of a tool for performing the prone maneuver. Rev Bras Ter Intensiva, 2017, 29: 131–141 (in Portuguese and English). [Medline] [CrossRef]
18) Rush University System for Health: Prone positioning for acute respiratory distress syndrome (ARDS). https://www.youtube.com/watch?v=lcBPaHQUvXY&t=8s (Accessed Feb. 10, 2024)
19) Nagai K, Tateuchi H, Takashima S, et al.: Effects of trunk rotation on scapular kinematics and muscle activity during humeral elevation. J Electromyogr Kinesiol, 2013, 23: 679–687. [Medline] [CrossRef]
20) Kaminski TR, Bock C, Gentile AM: The coordination between trunk and arm motion during pointing movements. Exp Brain Res, 1995, 106: 457–466. [Medline] [CrossRef]
21) Thakur N, Shah D: Interventional study designs. Indian Pediatr, 2021, 58: 1171–1181. [Medline] [CrossRef]
22) Woodworth JA: Nursing students' home care learning delivered in an innovative 360-degree immersion experience. Nurse Educ, 2022, 47: E136–E139. [Medline] [CrossRef]
23) Kang SJ, Min HY: Psychological safety in nursing simulation. Nurse Educ, 2019, 44: E6–E9. [Medline] [CrossRef]
24) Stratton SJ: Population research: convenience sampling strategies. Prehosp Disaster Med, 2021, 36: 373–374. [Medline] [CrossRef]
25) Charalambous C, Koulori A, Vasilopoulos A, et al.: Evaluation of the validity and reliability of the Waterlow pressure ulcer risk assessment scale. Med Arh, 2018, 72: 141–144. [Medline] [CrossRef]
26) Lucchini A, Russotto V, Barreca N, et al.: Short and long-term complications due to standard and extended prone position cycles in COVID-19 patients. Intensive Crit Care Nurs, 2022, 69: 103158. [Medline] [CrossRef]
27) Koizumi M: Trends and issues related to pressure ulcers in prone positioning during treatment of severe COVID-19. J Jpn Soc Wound Ostomy Cont Manage, 2022, 26: 27–31.
28) Ohura T: Latest concept of pressure ulcers-rehabilitation and pressure ulcers. Gen Rehabil, 2004, 32: 497–503.
29) Toyoda T, Kurosawa K, Fukuda D, et al.: Position-related differences in the passive shoulder rotation range of motion. Rigakuryoho Kagaku, 2021, 36: 403–408. [CrossRef]
30) McKay MJ, Baldwin JN, Ferreira P, et al. 1000 Norms Project Consortium: Normative reference values for strength and flexibility of 1,000 children and adults. Neurology, 2017, 88: 36–43. [Medline] [CrossRef]
31) Hallaçeli H, Uruç V, Uysal HH, et al.: Normal hip, knee and ankle range of motion in the Turkish population. Acta Orthop Traumatol Turc, 2014, 48: 37–42. [Medline] [CrossRef]