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Curvilinear Supine Position for Pressure Injury Prevention in Pediatric Cardiac Surgery Patients: A Randomized Controlled Trial

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Abstract: *Background:* Pressure injury (PI) is a prevalent complication in pediatric cardiac surgery, with higher incidence than in general pediatric populations due to children's thin skin, underdeveloped subcutaneous tissue, and prolonged intraoperative pressure. Objective: To evaluate the effectiveness of the curvilinear supine position (CSP) in preventing PI among children undergoing congenital heart disease (CHD) surgery. *Methods*: Between October 2024 and February 2025, a single-center randomized controlled trial was conducted. Of the 80 children initially enrolled for congenital heart disease (CHD) surgery, 77 (aged 1 month to 14 years) completed the study and were included in the final analysis after 3 were excluded due to protocol violations. Participants were randomly assigned to the CSP group (n = 38) or the conventional supine position group (n = 39). *Results:* The incidence of PI was significantly lower in the CSP group (2.6%) compared to the control group (20.5%) (p = 0.029). Postoperative LDH levels were also significantly reduced in the CSP group (422.67 ± 86.52 U/L vs. 592.92 ± 215.71 U/L; p = 0.031), while preoperative LDH and surgical variables (e.g., cardiopulmonary bypass time) were comparable between groups. Although the CSP group had a shorter hospital stay (17.24 vs. 22.51 days), the difference was not statistically significant (p = 0.085). Caregiver satisfaction was significantly higher in the CSP group (100.0% vs. 84.6%; p = 0.025). *Conclusion:* CSP effectively reduces PI incidence, mitigates tissue injury, and enhances caregiver satisfaction in pediatric cardiac surgery, offering a safe and feasible strategy for perioperative PI prevention.

Keywords: Curvilinear supine position; Pressure injury; Children; Perioperative nursing; Cardiac surgery

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1. Introduction

Pressure injury (PI) is a common complication among pediatric patients undergoing cardiac surgery [1]. Children are particularly vulnerable due to their thinner epidermal layers, immature skeletal development, and reduced soft tissue padding over bony prominences, which offer less cushioning against prolonged pressure. Additionally, their limited cardiovascular compensatory capacity increases susceptibility to localized ischemia during extended surgical procedures, thereby elevating PI risk compared to adults [2–4]. Epidemiological data indicate that the incidence of PI in children undergoing cardiac surgery ranges from 16.9% to 25%, significantly higher than that observed in general pediatric inpatients [5]. PIs not only prolong hospital stays and increase healthcare costs but may also lead to serious complications such as infection, ultimately impairing postoperative recovery [6,7]. Therefore, identifying effective preventive strategies for PI in this population is of critical clinical importance.

The curvilinear supine position (CSP) is a positioning technique that utilizes specialized support surfaces or adjustable operating table segments to align with the patient's natural spinal curvature.

By increasing the contact area between the body and the supporting surface, CSP aims to reduce localized interface pressure and mitigate the risk of PI development [8]. While CSP has demonstrated promising results in adult surgical populations, evidence regarding its application in pediatric surgery, particularly in children undergoing cardiac procedures, remains scarce, with a notable lack of rigorous efficacy evaluations [9–12].

This study aims to investigate the impact of CSP on PI-related outcomes in children undergoing cardiac surgery, thereby providing evidence-based insights to optimize perioperative PI prevention protocols in pediatric cardiac care.

2. Materials and methods

2.1. Study participants

This study enrolled 80 pediatric patients who underwent congenital heart surgery in the cardiac surgery department of a tertiary hospital between October 2024 and February 2025.

2.1.1. Inclusion criteria

(1) Age between 1 month and 14 years;
(2) Scheduled for surgery in the supine position;
(3) No preoperative pressure injury (PI);
(4) Voluntary participation with informed consent provided by the patient's legal guardian.

2.1.2. Exclusion criteria

(1) Presence of comorbid systemic diseases (e.g., severe hepatic or renal impairment);
(2) Preexisting dermatological conditions that could interfere with skin assessment.

2.1.3. Sample size estimation

Based on previously published data, the expected incidence of PI was 25% in the control group and 5% in the intervention group [5]. Using PASS 15.0 software with a two-sided significance level of $\alpha = 0.05$ and statistical power of 90% ($\beta = 0.10$), the minimum required sample size was calculated to be 36 participants per group. Anticipating a 10% attrition rate, a total of 80 patients were ultimately recruited and randomly allocated to either

the intervention or control group.

All procedures involving human participants were conducted in accordance with the ethical standards of the institutional research ethics committee (Approval No.: 2024178). Written informed consent was obtained from the legal guardians of all enrolled participants prior to study initiation.

2.2. Study design

2.2.1. Group allocation

A randomized controlled trial design was employed. The 80 enrolled patients were assigned to either the intervention or control group using a random number table, following their order of admission, with 40 participants allocated to each group.

During the study, three participants were excluded due to violation of eligibility criteria: one in the intervention group developed abnormal liver function, another had atopic dermatitis; and one in the control group presented with eczema, conditions that could confound skin assessment.

Consequently, 77 participants completed the study: 38 in the intervention group and 39 in the control group. The intervention group received care in the curvilinear supine position (CSP), while the control group was positioned in the standard supine position throughout surgery.

2.2.2. Blinding procedure

Blinding was implemented for pressure injury (PI) assessors. Two intensive care unit (ICU) nurses who were not involved in intraoperative care were designated as independent evaluators. Prior to assessment, they were blinded to the participants' group allocation. Both assessors received standardized training to ensure consistency and reliability in PI evaluation.

2.2.3. Intervention protocol

Both groups received standard perioperative care for congenital heart disease (CHD) surgery, including preoperative fasting, intraoperative vital sign monitoring, and routine postoperative nursing care. On this foundation, different positioning strategies were implemented.

(1) Control group

Patients were placed in the conventional supine position. Pressure injury (PI) prevention measures followed the Expert Consensus on Prevention of Intraoperative Acquired Pressure Injury [13]. Specifically, the operating table remained level throughout surgery. Memory foam positioning pads were placed under the heels and sacrococcygeal region. Position adjustments were made only as clinically required by the surgical procedure, without intentional modification of joint angles or use of specialized supports to alter body alignment.

(2) Intervention group

In addition to standard care, patients were positioned using the curvilinear supine position (CSP), as follows:

(3) Positioning protocol

For children with height ≥ 150 cm: the headboard, backrest, and seat sections of the operating table were elevated by 10°, while the leg section was lowered by 10°. For children with height < 150 cm: a defatted cotton pad (6–8 cm thick) was placed beneath the shoulders to gently elevate the thorax; a full-length

pressure-relieving pad was placed under the calves to maintain knee flexion at 5–10°; and an inflatable head cushion was used to support the head. The goal was to align the body with its natural physiological curvature, maximize contact surface area with the supporting surface, and minimize pressure on bony prominences [11,12].

Skin assessments were performed by ICU nurses using the blanching test (applying finger pressure to erythematous areas for 3 seconds and observing for blanching) at four time points: during handover from the operating room, and at 24, 48, and 72 hours postoperatively. Any occurrence of pressure injury was documented according to standardized criteria.

2.2.4. Outcome measures

(1) Primary outcome

Incidence of pressure injury (PI): Assessed according to the 2019 guidelines of the National Pressure Injury Advisory Panel (NPIAP) [14]. All assessing nurses received standardized training prior to evaluation. Any skin lesion classified as Stage I or higher was defined as a PI occurrence.

(2) Secondary outcomes

Length of hospital stay: Total number of days from admission to discharge. Serum lactate dehydrogenase (LDH) levels: Venous blood samples were collected at two time points on the day before surgery and 24 hours postoperatively, and analyzed using an automated biochemical analyzer. Caregiver satisfaction: Measured using the Caregiver Satisfaction Survey on PI Prevention, a validated instrument comprising five dimensions: preoperative education, postoperative skin assessment, effectiveness of preventive interventions, communication, and overall nursing care. The scale demonstrated strong internal consistency (Cronbach's $\alpha = 0.85$) and content validity (Content Validity Index, CVI = 0.92). Total scores range from 0 to 100, with scores ≥ 80 indicating "satisfied". Caregiver satisfaction rate was calculated as: Satisfaction rate (%) = (Number of satisfied cases / Total number of cases) × 100%

2.2.5. Statistical analysis

Data were analyzed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA).

Continuous variables were first tested for normality using the Shapiro–Wilk test. Data that followed a normal distribution are presented as mean ± standard deviation (mean ± SD) and compared between groups using the independent-samples *t*-test. Non-normally distributed continuous data are reported as median (interquartile range [IQR]), i.e., M (Q_1, Q_3), and analyzed using the Mann–Whitney U test.

Categorical variables are expressed as frequencies and percentages (n [%]) and compared between groups using the chi-square (χ^2) test or Fisher's exact test, as appropriate.

A two-sided p value < 0.05 was considered statistically significant.

3. Results

3.1. Baseline characteristics

There were no statistically significant differences between the two groups in baseline characteristics, including sex, age, and body weight ($p > 0.05$). Detailed data are presented in **Table 1**.

Table 1. Comparison of baseline characteristics between the two groups of pediatric patients

Variable	Control group (n = 39)	Intervention group (n = 38)	Test statistic	*p* value
Sex, n (%)			0.108[a]	0.742
Male	23 (59.0)	21 (55.3)		
Female	16 (41.0)	17 (44.7)		
Age (months), median (IQR)	8.0 (1.0, 24.0)	12.0 (5.0, 48.0)	-1.72[b]	0.086
Weight (kg), median (IQR)	6.8 (4.3, 13.0)	9.4 (6.0, 15.1)	-1.58[b]	0.115
Height (cm), median (IQR)	66.0 (53.0, 95.0)	79.0 (63.8, 102.3)	-1.73[b]	0.084
Preoperative albumin (g/L), mean ± SD	40.01 ± 4.26	41.23 ± 4.20	0.976[c]	0.335
Preoperative hemoglobin (g/L), mean ± SD	121.95 ± 24.68	126.24 ± 25.02	0.757[c]	0.451
Preoperative CORN score, mean ± SD	11.03 ± 0.84	11.05 ± 0.96	-0.131[c]	0.896
Diagnosis, n (%)			30.003[d]	0.671
Atrial septal defect	12 (30.8)	14 (36.8)		
Ventricular septal defect	16 (41.0)	17 (44.8)		
Patent ductus arteriosus	5 (12.8)	4 (10.5)		
Anomalous pulmonary venous return	3 (7.7)	1 (2.6)		
Aortic valvuloplasty	1 (2.6)	0 (0.0)		
Pulmonary valvuloplasty	2 (5.1)	2 (5.3)		

Notes.

[a] Chi-square test;

[b] Mann–Whitney U test (reported as *Z* statistic);

[c] Independent-samples *t*-test;

[d] Fisher–Freeman–Halton exact test was used because 97.1% of cells had expected frequencies < 5.

3.2. Comparison of pressure injury incidence at pressure-prone sites between groups

Pressure injuries (PIs) occurred in 8 patients in the control group, all classified as Stage I (2 at the sacrococcygeal region and 6 at the occiput). In the intervention group, only 1 patient developed a Stage I PI at the sacrococcygeal area. The incidence of PI was significantly lower in the intervention group compared to the control group (p = 0.029). Detailed results are presented in **Table 2**.

Table 2. Incidence of pressure injury in the two groups

Variable	Control group (n = 39)	Intervention group (n = 38)	*p* value
Pressure injury, n (%)			0.029[a]
Yes	8 (20.5)	1 (2.6)	
No	31 (79.5)	37 (97.4)	

Note. [a] p value calculated using Fisher's exact test.

3.3. Comparison of length of hospital stay between groups

There was no statistically significant difference in length of hospital stay between the control group and the intervention group (p = 0.085). See **Table 3** for details.

3.4. Comparison of serum lactate dehydrogenase (LDH) levels before and after surgery

There was no statistically significant difference in preoperative LDH levels between the two groups ($p > 0.05$). However, postoperative LDH levels were significantly lower in the intervention group compared to the control group ($p = 0.031$).

To account for potential confounding factors, we further analyzed variables such as operative duration and cardiopulmonary bypass time.

No significant between-group differences were observed for these factors ($p > 0.05$), suggesting that the observed LDH reduction was unlikely attributable to procedural variability. Detailed data are provided in **Table 3**.

Table 3. Comparison of length of hospital stay and lactate dehydrogenase (LDH) levels between the two groups

Variable	Control group (n = 39)	Intervention group (n = 38)	Test statistic	*p* value
Length of hospital stay (days, mean ± SD)	22.51 ± 10.90	17.24 ± 7.91	-1.747[a]	0.085
Preoperative LDH (U/L, mean ± SD)	305.72 ± 114.96	290.82 ± 115.99	-0.566[a]	0.573
Postoperative LDH (U/L, mean ± SD)	592.92 ± 215.71	422.67 ± 86.52	-2.378[a]	0.031
Operative time (minutes, mean ± SD)	205.05 ± 112.91	174.61 ± 70.87	-1.413[a]	0.162
Cardiopulmonary bypass time (minutes, mean ± SD)	142.46 ± 102.85	113.08 ± 71.26	-1.460[a]	0.149

Note. [a]*p* values were calculated using independent-samples *t*-tests.

3.5. Comparison of caregiver satisfaction between the two groups

Caregiver satisfaction was significantly higher in the intervention group than in the control group ($p = 0.025$). Specifically, 33 out of 39 caregivers (84.6%) in the control group reported satisfaction, compared to all 38 caregivers (100%) in the intervention group. These results are summarized in **Table 4**.

Table 4. Comparison of caregiver satisfaction between the two groups

Variable	Control group (n = 39)	Intervention group (n = 38)	*p* value
Caregiver satisfaction, n (%)			0.025[a]
Satisfied	33 (84.6)	38 (100.0)	
Not satisfied	6 (15.4)	0 (0.0)	

Note. [a]*p* value was calculated using Fisher's exact test.

4. Discussion

4.1. Effectiveness of the curvilinear supine position (CSP) in reducing pressure injury incidence

Pressure injury (PI) arises from prolonged localized pressure that compromises tissue perfusion, leading to ischemia and hypoxia [14]. Children are particularly vulnerable due to their thinner skin, reduced subcutaneous fat, and insufficient cushioning over bony prominences, which collectively diminish their tolerance to mechanical stress [3,15]. In the conventional supine position, pressure becomes concentrated on these bony areas, with local interface pressures often exceeding 100 mmHg, well above capillary closing pressure (about 32 mmHg), thereby predisposing tissues to damage [11,16].

In this study, the intervention group was positioned using the curvilinear supine position (CSP), which aligns the body along its natural physiological curvature by adjusting operating table angles or employing supportive positioning pads. This approach increases the contact surface area between the patient's back and buttocks and the supporting surface. Additionally, heel-offloading pads and an inflatable head cushion were used to further redistribute pressure. Collectively, these measures effectively minimized sustained focal pressure on vulnerable tissues.

Consistent with our hypothesis, the PI incidence in the CSP group was significantly lower than in the control group. This finding aligns with the results of a recent meta-analysis by Chen et al., thereby reinforcing the evidence that CSP is an effective strategy for preventing intraoperative pressure injuries in pediatric patients undergoing cardiac surgery [12].

4.2. Effect of CSP on length of hospital stay

Length of hospital stay is influenced by multiple factors, including surgical outcomes and postoperative complications. Pressure injury (PI), as a common iatrogenic complication, has been associated with prolonged hospitalization [17,18]. In the present study, the intervention group exhibited a slightly shorter duration of hospital stay compared to the control group; however, this difference did not reach statistical significance ($p = 0.085$). This lack of significance may be attributed to the fact that, in pediatric congenital heart disease (CHD) surgery, length of stay is primarily determined by the recovery of cardiac function and hemodynamic stability, factors that likely overshadowed the potential impact of PI prevention on hospital duration.

4.3. Impact of CSP on serum lactate dehydrogenase (LDH) levels

Lactate dehydrogenase (LDH) is a sensitive, albeit non-specific, biomarker of tissue injury. When skin and subcutaneous tissues experience ischemia and hypoxia due to prolonged pressure, cellular damage occurs, leading to cell membrane rupture and subsequent release of LDH into the bloodstream [19]. However, serum LDH levels can also be influenced by various systemic factors, including hemolysis, myocardial injury, hepatic dysfunction, and cardiopulmonary bypass [20,21].

In this study, preoperative LDH levels were comparable between the two groups. Postoperatively, LDH concentrations were significantly lower in the intervention group than in the control group. Notably, no significant differences were observed between groups in potential confounding variables such as operative duration and cardiopulmonary bypass time. These findings suggest that the curvilinear supine position (CSP) may mitigate local tissue pressure, improve microcirculatory perfusion at pressure-prone sites, and thereby reduce cellular necrosis, ultimately leading to decreased LDH release.

4.4. Impact of CSP on caregiver satisfaction

Caregiver satisfaction is a key indicator of nursing care quality. Parents and family members of children undergoing congenital heart disease (CHD) surgery often exhibit heightened concerns regarding surgical risks and their child's pain, leading them to place greater emphasis on the quality and communication of nursing interventions [22].

In the intervention group, the implementation of the curvilinear supine position (CSP) effectively prevented pressure injuries and minimized postoperative skin complications. Furthermore, caregivers received detailed preoperative explanations of the positioning care plan and timely updates regarding their child's skin condition

during the perioperative period. These practices fostered greater trust in the nursing team and enhanced perceived care quality [23].

Consistent with these observations, caregiver satisfaction was significantly higher in the intervention group compared to the control group. This finding suggests that CSP not only offers clinical benefits but also positively influences the overall healthcare experience of families, reinforcing its value as a patient- and family-centered intervention.

4.5. Limitations

This study has several limitations. First, it was conducted at a single center with a relatively small sample size, which may limit the generalizability of the findings. Second, we did not perform a dose–response analysis to evaluate how specific parameters of the curvilinear supine position (CSP), such as angle of inclination or type of positioning support which might influence outcomes. Future research should involve multicenter, large-scale randomized controlled trials to further validate the efficacy of CSP, optimize its procedural parameters, and provide more robust evidence to guide positioning protocols in pediatric cardiac surgery.

5. Conclusion

The curvilinear supine position (CSP) was associated with a reduced incidence of pressure injury, less tissue damage at pressure-prone sites, and higher caregiver satisfaction among children undergoing cardiac surgery. These findings support CSP as a safe and feasible perioperative intervention that may contribute to improved pressure injury prevention in pediatric cardiac surgical care.

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Disclosure statement

The authors declare no conflict of interest.

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