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Assessment of Factors Leading to Patient Positioning Errors During Surgical Procedures in Tertiary Care Hospital

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ABSTRACT

Background: Patient positioning errors during surgical procedures are a significant concern as they can lead to serious intraoperative and postoperative complications, particularly pressure injuries.
Objective: This study aimed to assess the factors leading to patient positioning errors in the operating room of a tertiary care hospital, identify common positioning errors, determine patient-, procedure-, and team-related factors, and evaluate their association with pressure injuries.
Methods: A descriptive cross-sectional study design was employed over a period of six months. A total of 168 operation theatre (OT) staff members were selected using a convenience sampling technique. Data were collected through a structured self-administered questionnaire and analyzed using SPSS version 26. Descriptive statistics were applied, and statistical analysis was performed using the Chi-square test.
Results: The results revealed that most positioning errors were of low severity, with the majority of cases falling under error score 1. However, errors were commonly observed across different surgical positions, with the highest frequency in the supine position. Statistically significant associations were found between positioning errors and surgical specialty ($p = 0.003$) as well as duration of surgery ($p < 0.001$), indicating that longer and more complex procedures increased the risk of errors. Furthermore, a strong association was observed between patient positioning and the development of pressure injuries ($p < 0.001$), with the highest occurrence reported in supine, lithotomy, and prone positions.
Conclusion: Although most positioning errors were of low severity, they occurred frequently and were significantly associated with procedure-related factors. Improper and prolonged positioning increases the risk of pressure injuries. Therefore, strict adherence to positioning protocols, continuous monitoring, and proper training of surgical teams are essential to enhance patient safety and reduce complications.

Keywords: Patient Positioning, Medical Errors, Intraoperative Complications, Surgical Procedures, Operative, Tertiary Care Centers

INTRODUCTION

Acute asthma exacerbations remain a leading cause of pediatric Patient positioning errors are a major cause of intraoperative complications including pressure injuries. Nevertheless, the factors contributing specifically to pressure injuries caused by patient positioning in the operating room have not been thoroughly studied. Pressure injuries during surgery are primarily caused by prolonged immobility, loss of sensation due to anesthesia, and continuous pressure, which reduce blood flow and damage tissues. The risk is higher in longer surgeries and certain surgical positions. Tissue damage occurs both from restricted circulation and direct pressure on cells, highlighting the importance of vigilant monitoring and preventive measures during operations. Pressure injuries are localized skin and tissue, usually over bony areas, caused by prolonged pressure or shear. They occur when sustained pressure leads to reduced blood flow and tissue death, but research shows that direct tissue deformation can also cause rapid cell damage even before blood flow is affected. In surgery, improper positioning, prolonged pressure, and inadequate protection can cause pressure injuries. Patients in long procedures such as cardiac, thoracic, vascular, abdominal, and orthopedic surgeries are at higher risk due to extended operating times, rigid tables, equipment, and fixed positions that increase pressure and reduce tissue perfusion. [1]. Ensuring proper patient positioning on the operating table during surgery is crucial for achieving optimal anatomical exposure, facilitating access to necessary equipment, maintaining patient comfort, and reducing the risk of injuries. Patient positioning is considered a collective responsibility of the entire surgical team [2]. The use of appropriate positioning aids, such as modern gel-filled supports for the head and limbs or the floating limb

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technique, helps to reduce the occurrence of surgery-related pressure injuries [3].

Pressure injuries are a common problem among hospitalized adults worldwide, with a pooled prevalence of about 12.8% and hospital-acquired rates around 8.4% [4]. Surgical patients are particularly vulnerable, with approximately 17% developing postoperative pressure ulcers. The prevalence varies depending on surgery type, patient factors, and hospital stay duration, ranging from 0.05% to 74.2% in different studies. These figures highlight the global burden of pressure injuries. Identifying at-risk patients and implementing preventive measures is essential to reduce these complications [5].

Hospital-acquired pressure injuries are a significant concern in intensive care and high-risk settings across Asia and the Eastern Mediterranean. A recent meta-analysis reported a pooled prevalence of approximately 16.6% in ICUs within the region. This prevalence highlights the burden of pressure injuries among vulnerable hospitalized patients. Variations in healthcare standards, patient characteristics, and hospital resources contribute to this issue. These findings emphasize the need for effective preventive strategies and thorough risk assessments to reduce pressure-related complications [6].

A study conducted at North West General Hospital, Peshawar, identified 99 patients with pressure ulcers, with the majority being male (65.7%) and an average age of around 60 years. Most patients (87.9%) had only one ulcer, with Stage II ulcers being the most frequent (43.1%) and Stage IV ulcers being uncommon (3.3%). The gluteal and sacral areas were the most affected. The highest rates were observed in the COVID-19 ward (25.3%) and neurosurgery ward (20.2%), highlighting the greater risk in critically ill and immobile patients. These findings show that pressure ulcers are a notable concern in Pakistani hospitals [7].

Damage to the skin caused by pressure injuries can be painful, disfiguring, and expensive to manage. According to the National Pressure Injury Advisory Panel (NPIAP), a pressure injury is a localized injury to the skin and underlying soft tissues, typically occurring over bony areas or at sites where medical devices exert pressure [8]. Pressure injuries are a common and significant problem in healthcare worldwide. Pressure injuries develop from prolonged pressure on the skin and underlying tissues, especially in people with limited mobility. They range from mild redness to severe ulcers and can cause significant clinical, financial, and psychosocial impact [9].

Patient positioning is vital in surgery because it affects surgical access, anesthesia management, and complication prevention. While the lead surgeon is primarily responsible, the entire surgical team must help ensure safe positioning. Proper OR setup and collaborative planning are essential before the procedure begins [10]. Pressure injuries, or pressure ulcers, are common yet preventable wounds that usually develop over bony areas or from medical devices. They damage the skin and underlying tissues, increase morbidity and mortality, reduce quality of life, and often prolong hospital stays. Advanced age, comorbidities, and limited mobility increase the risk of pressure injuries. Both low and very high BMI (Body Mass Index), malnutrition, and possibly male gender are additional risk factors. Studies show a U-shaped relationship between BMI and PIs, with underweight and obese patients being more susceptible [11].

The EPUAP/NPIAP (2019) (European Pressure Ulcer Advisory Panel / National Pressure Injury Advisory Panel) guidelines classify pressure injuries from mild skin redness (Stage 1) to severe full-thickness tissue loss involving muscle or bone (Stage 4). Some injuries are unstageable due to slough or scar, while deep tissue injuries involve damage beneath intact or discolored skin. Knowing these stages supports early detection, prevention, and timely management, especially in surgical patients [12].

Pressure injuries are preventable yet serious healthcare issues that increase patient morbidity, mortality, and hospital costs. Early risk identification and protective measures are crucial, with nurses playing a key role in assessing, caring for, and preventing injuries during the perioperative period [13]. In addition, a systematic review and meta-analysis of intraoperative positioning incidents revealed that different surgical positions such as supine, lithotomy, prone, Trendelenburg, and lateral are associated with adverse outcomes, including pressure ulcers, nerve injuries, and musculoskeletal or vascular damage. This indicates that nearly all commonly used operative positions carry an inherent risk of patient injury [14].

The effectiveness of operating-room nurses in preventing surgery-related pressure injuries largely depends on their knowledge and attitudes regarding these injuries. Enhancing nurses' knowledge increases their awareness and equips them to make informed decisions about prevention and care. Conversely, negative attitudes towards pressure injuries can hinder the implementation of preventive strategies. Studies conducted among ICU, clinical, and OR nurses have shown that nurses generally hold positive attitudes towards pressure injury prevention. Additionally, training on the topic, adherence to established guidelines, and greater work experience have been found to positively influence their attitudes [15].

Improper patient positioning in the operating room can cause considerable harm. A recent cross-sectional study found that 25.7% of surgical patients developed Stage I pressure injuries postoperatively, with the supine position being the most frequently associated risk factor. Previous studies have mainly examined pressure injuries in intensive care or general clinical settings, leaving limited knowledge about those that develop specifically in the operating room during surgical procedures, particularly as a result of patient positioning. Factors such as prolonged pressure, firm operating tables, and certain positions including supine and lateral have been linked to a higher risk of pressure injuries during surgery. To address this gap in the literature, the present study aims to investigate the risk factors associated with positioning-related pressure injuries in the operating room [1].

Medical devices, especially respiratory and feeding devices, frequently cause pressure injuries, often affecting the head and neck. Device-related pressure injuries (MDRPIs) can occur in 30–70% of cases. Awareness and monitoring are essential for prevention [16].

Objective of study

To identify the common patient positioning errors occurring during surgical procedures.

To determine the key factors (patient-related, procedure-related, and team-related) leading to positioning errors.

To assess the association between positioning errors and the development of pressure injuries (PIs).

METHODOLOGY

Study Design and Setting

A descriptive cross-sectional study design was employed to assess factors contributing to patient positioning errors among operating theatre (OT) staff at a single point in time. The study was conducted in the Operation Theatre Department of a tertiary care hospital providing surgical services across multiple specialties. The setting was selected because of the diverse surgical workload and the involvement of multidisciplinary OT personnel in patient preparation, transfer, positioning, and intraoperative care.

Study Duration and Participants

The study was conducted over a period of six months. A total of

168 OT staff members were included in the study, representing different professional categories involved in perioperative patient care and positioning. Participants were recruited using a convenience sampling technique. Staff members who were available during their scheduled working hours and met the predefined eligibility criteria were approached for participation.

Eligibility Criteria

OT staff members were eligible for inclusion if they had at least six months of professional experience and were directly involved in patient positioning during surgical procedures. This minimum experience requirement was applied to ensure that participants had adequate exposure to routine positioning practices and associated challenges. Interns, students, and staff members who were not directly engaged in patient positioning were excluded from the study.

Data Collection Tool

Data were collected using a structured, self-administered questionnaire developed following a review of relevant published literature and established considerations related to patient positioning practices. The questionnaire was designed to obtain information regarding participants' professional characteristics, knowledge and practices related to patient positioning, and factors that may contribute to positioning errors. Participants completed the questionnaire independently to minimize interviewer influence and facilitate standardized data collection.

Data Analysis

The collected data were coded, entered, and analyzed using Statistical Package for the Social Sciences (SPSS), Version 26. Descriptive statistics were used to summarize the study variables. Categorical variables were presented as frequencies and percentages, while continuous variables were summarized using appropriate measures of central tendency and dispersion. Associations between categorical variables were assessed using the chi-square test. The level of statistical significance was set at $p < 0.05$. The analysis was performed systematically to identify significant associations between relevant participant characteristics, workplace factors, and patient positioning errors.

RESULTS

The results of the present study demonstrated several statistically significant associations between surgical positioning–related factors and the development of post-operative pressure injury. Chi-square analysis revealed that estimated duration of surgery, patient positioning during surgery, and positioning error score were significantly associated with post-operative pressure injury and positioning-related outcomes ($p < 0.05$). The findings indicated that longer surgical procedures and higher positioning error scores were linked with an increased occurrence of pressure injuries. Moreover, pressure injuries were more frequently observed among patients placed in supine and prone positions compared to other surgical positions. Overall, these results highlight the important role of proper patient positioning and duration of surgery in minimizing positioning errors and reducing the risk of post-operative pressure injuries. However, some findings should be interpreted cautiously because a number of cells had expected counts less than 5, which may affect the reliability of certain Chi-square test results.

Table 1. Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	72.846[a]	36	.000
Likelihood Ratio	65.426	36	.002
N of Valid Cases	168		

Duration of Surgery / Positioning Error Score

Estimated duration of surgery	Minimum	1	2	3	3–5	5
<1 hr	21	9	0	1	1	0
1–2 hrs	50	10	0	1	3	1
2–4 hrs	37	0	5	2	5	1
4–6 hrs	11	0	0	0	0	1
>6 hrs	1	0	0	0	0	0
Total	120	19	5	4	9	3

As shown in Table 1, the association between estimated duration of surgery and positioning error score was examined using the Chi-square test. The findings revealed a statistically significant association between estimated duration of surgery and positioning error score (Pearson $\chi^2 = 72.846$, df = 36, $p < 0.001$). This indicates that positioning error scores varied significantly according to the estimated duration of surgery. The crosstabulation showed that most cases with shorter surgical duration, particularly less than 1 hour and 1–2 hours, were concentrated in the lower positioning error score categories, whereas comparatively higher error scores were more frequently observed in procedures lasting 2–4 hours and above. However, this result should be interpreted with caution because 44 cells (88.0%) had expected counts less than 5, and the minimum expected count was 0.01, indicating that the assumptions of the Chi-square test were not fully met. Therefore, although a statistically significant relationship was observed, the reliability of this finding may be limited.

Figure 1. Duration of Surgery / Positioning Error Score

Patient Positioning / Pressure Injury

Patient positioning during surgery	Yes	No	Total
Supine	38	53	91
Prone	16	1	17
Lateral	12	2	14
Lithotomy	28	6	34
Trendelenbrug	1	0	1
Fowler	10	0	10
Other	0	1	1
Total	105	63	168

Figure. 1

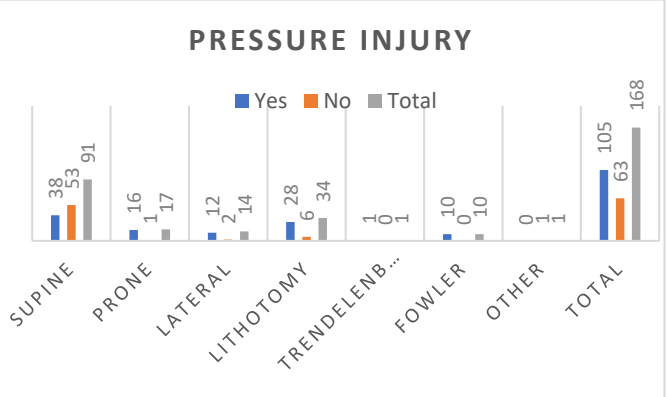

Table 2. Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	41.158[a]	6	.000
Likelihood Ratio	47.839	6	.000
Linear-by-Linear Association	23.543	1	.000
N of Valid Cases	168		

As shown in Table 2, the association between patient positioning during surgery and the development of post-operative pressure injury was examined using the Chi-square test. The findings revealed a statistically significant association between patient positioning during surgery and the development of post-operative pressure injury (Pearson $\chi^2 = 41.158$, df = 6, $p < 0.001$). This indicates that the occurrence of pressure injury differed significantly according to the patient's surgical position. The crosstabulation showed that the highest number of pressure injuries developed in patients placed in the supine position, followed by lithotomy, prone, lateral, and Fowler positions. In contrast, no pressure injury was reported in the 'other' category, while only one case was observed in the Trendelenburg position. However, this result should still be interpreted with some caution because 5 cells (35.7%) had expected counts less than 5, although the minimum expected count was 0.38. Therefore, the findings suggest a significant relationship between surgical positioning and post-operative pressure injury development in the study sample.

Table 3. Surgical Specialty / Pressure Injury

Surgical specialty	1	2	Total
General Surgery	29	26	55
Ortho	27	5	32
Neuro	0	1	1
Cardiac	13	1	14
ENT	6	14	20
Gyane/Obs	16	14	30
Urology	14	2	16
Total	105	63	168

Table 4. Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	30.302[a]	6	.000
Likelihood Ratio	33.314	6	.000
Linear-by-Linear Association	.038	1	.846
N of Valid Cases	168		

As shown in Table 3, the association between surgical specialty and the development of post-operative pressure injury was examined using the Chi-square test. The findings revealed a statistically significant association between surgical specialty and the development of post-operative pressure injury (Pearson $\chi^2 = 30.302$, df = 6, $p < 0.001$). This indicates that the occurrence of post-operative pressure injury differed significantly across the categories included in the analysis. The crosstabulation showed that post-operative pressure injury was most frequently observed in the supine (n = 29) and prone (n = 27) groups, followed by Fowler (n = 16), other (n = 14), and lithotomy (n = 13), while no pressure injury case was observed in the lateral group. In contrast, the highest frequencies in the non-pressure injury category were found in the supine (n = 26), Trendelenburg (n = 14), and Fowler (n = 14) groups. Moreover, only 2 cells (14.3%) had expected counts less than 5, and the minimum expected count was 0.38, indicating that the assumptions of the Chi-square test were largely satisfied. Therefore, the findings suggest a reliable and statistically significant relationship between surgical specialty and the development of post-operative pressure injury in the study sample.

As shown in Table 4, the association between positioning error score and the development of post-operative pressure injury was examined using the Chi-square test. The findings revealed a statistically significant association between positioning error score and the development of post-operative pressure injury (Pearson $\chi^2 = 35.913$, df = 9, $p < 0.001$). This indicates that the occurrence of post-operative pressure injury varied significantly according to the positioning error score. The crosstabulation showed that the majority of pressure injury cases were observed in the minimum error score category (n = 78), followed by the 3–5 score category (n = 9) and other higher score categories, whereas comparatively fewer cases were observed in lower error score categories such as score 1 (n = 4) and score 2 (n = 0). In contrast, most cases without pressure injury were concentrated in the minimum (n = 42) and score 1 (n = 15) categories, with very few or no cases in higher score categories. These findings suggest that higher positioning error scores are associated with an increased likelihood of developing post-operative pressure injury. Therefore, a statistically significant relationship exists between positioning error score and pressure injury development in the study sample.

Table 5. Positioning Error Score / Pressure Injury Developed Post-op

Positioning Error Score	Yes	No	Total
<1	78	42	120
1	4	15	19
2	0	5	5
3	4	0	4
3–5	9	0	9
5	3	0	3
6	3	0	3
6–9	2	0	2
Rare Case	1	1	2
Zero	1	0	1
Total	105	63	168

Table. 6 Cumulative Frequency Table – Positioning Error Score

Positioning Error Score	Frequency (f)	Cumulative Frequency (cf)	Percentage (%)	Cumulative %
<1	120	120	71.4	71.4
1	19	139	11.3	82.7
2	5	144	3.0	85.7
3	4	148	2.4	88.1
3–5	9	157	5.4	93.5
5	3	160	1.8	95.3
6	3	163	1.8	97.1
6–9	2	165	1.2	98.3
Rare Case	2	167	1.2	99.5
Zero	1	168	0.5	100
Total	168	168	100%	100%

The cumulative distribution of positioning error scores showed that most patients (71.4%) had a positioning error score of less than 1, indicating that proper patient positioning was maintained in the majority of surgical procedures. Only a small proportion of patients demonstrated higher positioning error scores, while very few cases were categorized as rare or extreme errors. These findings suggest that overall positioning practices during surgery were generally satisfactory, although isolated cases with higher

error scores may increase the risk of postoperative pressure injuries.

DISCUSSION

The present study was conducted to assess the factors leading to patient positioning errors during surgical procedures and their association with pressure injuries. The findings revealed that the majority of positioning errors were of low severity, with most cases falling under error score 1. Although these errors were classified as minor, their frequent occurrence highlights that patient positioning remains an important concern in surgical settings. Even small positioning mistakes can compromise patient comfort, tissue perfusion, and overall surgical safety when they occur repeatedly or remain unnoticed for long periods. Therefore, the presence of frequent low-grade errors suggests the need for continuous monitoring and adherence to standard positioning guidelines during operative procedures.

Among the different surgical positions assessed in this study, the supine position demonstrated the highest frequency of positioning errors. This finding may be attributed to the fact that the supine position is the most commonly used position in surgical practice for a wide variety of procedures. Because of its routine use, healthcare staff may underestimate the risks associated with this position and become less vigilant regarding pressure point protection and proper body alignment. In addition, prolonged surgeries performed in the supine position may increase continuous pressure on areas such as the sacrum, occiput, heels, and shoulders, thereby increasing the likelihood of positioning-related complications. Although the supine position is generally considered safe and simple, improper padding or inadequate repositioning during long procedures can still result in significant patient harm.

The findings of the present study also showed that moderate to severe positioning errors were more frequently observed in prone and prolonged positioning cases. These positions are generally more complex and require careful handling of the patient's body alignment, airway management, and pressure point support. In the prone position, patients are particularly vulnerable to complications involving the face, chest, abdomen, knees, and nerves due to uneven pressure distribution. Similarly, lithotomy and lateral positions may place strain on nerves and muscles if maintained for extended durations. Therefore, the increased occurrence of higher error scores in these positions indicates that surgical complexity and prolonged immobility significantly contribute to positioning difficulties and complications.

Another important finding of this study was the statistically significant association between surgical specialty and positioning errors. Different surgical specialties involve different operative techniques, durations, equipment, and patient positioning requirements. For example, orthopedic, neurosurgical, and gynecological procedures often require complex positioning and longer operative times, which may increase the risk of positioning-related errors. The variation in positioning error rates among surgical specialties may also reflect differences in staff training, teamwork, and awareness regarding patient safety practices. These findings emphasize that positioning safety should not only depend on individual healthcare professionals but also on coordinated multidisciplinary teamwork and specialty-specific protocols.

The duration of surgery was also identified as a highly significant factor associated with positioning errors. Longer surgical procedures were found to be associated with higher severity of positioning errors and increased risk of pressure injuries. This finding supports the well-established concept that prolonged immobility contributes to sustained pressure over bony prominences, impaired blood circulation, and tissue ischemia, ultimately leading to pressure injury development. During lengthy surgeries, the patient remains unable to adjust body posture naturally, making them entirely dependent on the surgical team for pressure relief and protection. In addition, fatigue among healthcare staff during prolonged procedures may reduce attention to positioning details, further increasing the likelihood of errors.

The study further demonstrated a strong association between patient positioning and the development of pressure injuries. The highest number of pressure injuries was observed among patients placed in the supine position, followed by lithotomy and prone positions. This finding suggests that even frequently used surgical positions can become harmful if preventive measures are not consistently implemented. Pressure injuries not only increase patient discomfort and prolong recovery but may also contribute to longer hospital stays, increased healthcare costs, and reduced quality of life. The occurrence of pressure injuries in this study highlights the importance of using adequate positioning devices, pressure-relieving pads, and regular assessment of vulnerable body areas during surgery.

Furthermore, the statistically significant association between surgical specialty and pressure injury occurrence indicates that procedural characteristics and team practices play a major role in patient safety outcomes. Surgical teams working in high-risk specialties should receive regular education and competency-based training regarding safe positioning techniques and pressure injury prevention strategies. The use of standardized positioning checklists, evidence-based protocols, and continuous intraoperative monitoring may help reduce the frequency of positioning-related complications. Effective communication between surgeons, anesthetists, nurses, and operating room staff is also essential to ensure that patient positioning is maintained correctly throughout the procedure.

Overall, the findings of this study suggest that while most positioning errors are minor in severity, their cumulative effect can lead to serious complications, particularly during prolonged surgical procedures. The study highlights the importance of strict adherence to patient positioning protocols, early identification of risk factors, and implementation of preventive strategies to minimize pressure injuries and improve surgical outcomes. Continuous staff education, proper use of positioning aids, and collaborative teamwork are essential measures to enhance patient safety during surgery. Future studies with larger sample sizes and multicenter settings may provide further insight into effective interventions for reducing positioning errors and improving perioperative care practices.

CONCLUSION

Patient positioning errors are common during surgical procedures, although most are of low severity. However, factors such as surgical duration, type of surgery, and surgical specialty significantly influence the occurrence and severity of these errors. The study also confirms a strong association between improper positioning and the development of pressure injuries. Patients undergoing prolonged surgeries and those positioned in high-risk positions are more vulnerable to such complications. Therefore, patient positioning is a critical aspect of surgical care that requires careful attention, proper technique, and continuous monitoring to minimize risks and improve patient safety outcomes.

Recommendation

- Hospitals should implement standardized positioning protocols for all surgical procedures to ensure consistency in practice.
- Regular training and workshops should be conducted for surgical teams to improve knowledge and skills related to safe patient positioning.
- Special attention should be given to long-duration surgeries, with periodic reassessment of patient positioning during procedures.
- Use of pressure-relieving devices (such as cushions, pads, and supports) should be encouraged, especially for high-risk patients.
- Increased supervision and coordination among surgical team members should be ensured to reduce human errors.
- Future research should be conducted on larger populations and different healthcare settings to further validate these findings.

Limitations

- The study was conducted in a tertiary care hospital, which may limit the generalizability of the findings.
- The sample size, although adequate, may not fully represent all surgical populations.
- Only selected variables were studied; other potential factors such as patient comorbidities and staff experience were not explored in detail.
- Data collection relied on observational methods, which may introduce observer bias.
- The study focused on short-term outcomes and did not assess long-term complications of positioning errors.

Ethical Approval

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board (IRB)/Ethics Committee. (Approval No.: GDGO18/05-25).

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions

Conceptualization: Zarnish Fatima, Fakhra Fakhr
Methodology: Zarnish Fatima, Fakhra Fakhr, Ifra Noor
Data Collection: Muhammad Mohsin Yar
Formal Analysis: Zarnish Fatima, Ifra Noor
Writing – Original Draft: Zarnish Fatima
Writing – Review & Editing: All authors

Informed Consent

Written informed consent was obtained from the parents or legal guardians of all children included in the study.

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Conflict of Interest

The authors declare that they have no competing interests.

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Declaration of AI-Assisted Language Editing

The manuscript was authored by the research team and subsequently reviewed using Grammarly solely to improve English grammar, language clarity, and readability. No AI-assisted tool was used to generate or modify the scientific content, data analysis, interpretation, or conclusions; all content was critically reviewed and approved by the authors, who retain full responsibility for the manuscript in accordance with the ICMJE Recommendations.

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