International Journal of Biology and Life Sciences
ISSN: 2957-9511 | Vol. 15, No. 3, 2026

Characteristics and Associated Factors of Pressure Injury Development in Adult Intensive Care Unit Patients after Prone Invasive Ventilation: A Study based on the MIMIC-IV Database

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Abstract: **Objective:** To describe the documentation characteristics of pressure injuries in adult intensive care unit (ICU) patients receiving invasive mechanical ventilation following prone positioning, and to analyze associated factors. **Methods:** A retrospective cohort study was conducted using the MIMIC-IV v3.1 database, including adult patients admitted to the ICU for the first time who received invasive mechanical ventilation and had documented prone positioning. The index event was defined as the first recorded instance of prone positioning, and patients with prior documentation of pressure injury before this event were excluded. Multivariable logistic regression was used to analyze risk factors, and a 24-hour landmark analysis was performed to examine the association between the intensity of early nursing documentation during prone positioning and subsequent documentation of pressure injury. **Results:** A total of 297 patients were included, of whom 102 developed new pressure injury documentation following their first prone positioning episode, yielding an incidence of 34.34%. The model constructed from pre-index-event variables showed limited discriminatory ability (C-statistic = 0.594), and none of the candidate variables reached statistical significance. The 24-hour landmark analysis revealed that the number of nursing documentation entries within 24 hours after initial prone positioning was significantly associated with new pressure injury documentation beyond 24 hours (OR = 2.42, 95% CI: 1.39–4.19, P = 0.002). **Conclusion:** New pressure injury documentation is relatively common among adult ICU patients on invasive mechanical ventilation after prone positioning, and early nursing documentation intensity is associated with subsequent pressure injury documentation. Clinically, more intensive skin assessment and monitoring of high-risk pressure areas in prone patients are warranted, along with more standardized nursing documentation practices.

Keywords: Pressure Injury; Prone Position; Invasive Mechanical Ventilation; Intensive Care Unit; MIMIC.

1. Introduction

Prone positioning improves ventilation-perfusion ratios and oxygenation, and is an important intervention for patients with moderate-to-severe acute respiratory distress syndrome undergoing invasive mechanical ventilation. Early implementation of prolonged prone positioning has been shown to reduce 28-day and 90-day mortality rates in severely ill patients[1]. However, prolonged and repeated prone positioning subjects the facial, chest, iliac crest, knee, and genital areas to continuous pressure and shear forces. When combined with deep sedation, restricted mobility, inadequate circulatory perfusion, tissue edema, and pressure from medical devices, this increases the risk of pressure injuries. Studies indicate that the cumulative incidence of pressure injuries among adult ICU patients on prone positioning ranges from 25.7% to 48.5%[2, 3]. Pressure injuries are not merely localized skin problems; they can progress to deep or full-thickness tissue damage, complicating wound management, infection monitoring, and subsequent decompression strategies during prone positioning. Multicenter studies have also found that the severity of pressure injuries is progressively associated with increased risk of in-hospital mortality, longer ICU and hospital stays, higher healthcare costs, and greater readmission risk[4–6]. Pressure injury prevention is therefore an important patient safety concern during prone positioning therapy.

Previous studies have primarily focused on the incidence and prevention of pressure injuries associated with prone positioning, with insufficient attention to the timing of injury occurrence, documentation characteristics, and the temporal relationship between prone exposure and subsequent pressure injuries. The MIMIC-IV database contains patient demographics, vital signs, organ support data, clinical treatments, and time-stamped structured bedside records, providing a foundation for research using routine electronic health data[7, 8]. Therefore, this study uses the MIMIC-IV database to describe the incidence rate, temporal distribution, and clinical characteristics of pressure injury documentation after prone positioning in adult ICU patients receiving invasive mechanical ventilation. It further analyzes associations between baseline patient conditions, treatment factors, and the intensity of early prone positioning documentation (the exposure) and subsequent pressure injury documentation, to inform better risk monitoring, skin assessment, and nursing documentation practices.

2. Materials and Methods

2.1. General Information

This study used a retrospective cohort design and data from the Medical Information Mart for Intensive Care IV (MIMIC-IV) v3.1 database. The database contains de-identified electronic health records from Beth Israel Deaconess Medical Center in the United States, covering 2008 to 2022. The unit of analysis was patients' first ICU admission. Inclusion criteria were: 1) age ≥18 years at ICU admission; 2) receipt of invasive mechanical ventilation during the first ICU admission; and 3) at least one documented prone position during the invasive mechanical ventilation period. Exclusion criteria included: 1) documentation of pressure injury prior to or at the index event; and 2) inability to define the index event or follow-up boundaries due to missing critical time information. The first recorded instance of prone positioning during the invasive mechanical ventilation period was defined as the index event and served as the starting point for follow-up. Follow-up continued until the first occurrence of a pressure injury, ICU discharge, or death, whichever came first. MIMIC-IV is a controlled-access, de-identified database whose data sharing has been reviewed and approved by the Beth Israel Deaconess Medical Center Institutional Review Board, with an exemption from informed consent requirements. Researchers authenticated through PhysioNet and obtained database access after signing a data use agreement.

2.2. Data Extraction

Patient data were extracted using structured query language and included demographic characteristics, vital signs, laboratory values, comorbidities, disease severity scores, mechanical ventilation status, and nursing records. Demographic data included age, sex, and body mass index; disease-related data included major comorbidities, Sequential Organ Failure Assessment (SOFA) score, Acute Physiology Score III, vasopressor use, and laboratory parameters; prone-positioning-related data included the time of first prone positioning, the number of prone nursing documentation entries, and pressure injury records. Baseline variables were defined as the first or closest measurement to the index event before ICU admission.

2.3. Outcome Measures and Related Factors

The primary outcome was the occurrence of new pressure injury records from the index event until ICU discharge. For the analysis of related factors, only variables obtained before the index event were included to avoid using information that occurred after the outcome. Additionally, a landmark analysis was conducted, using the number of prone care documentation entries within 24 hours after the first prone position as the exposure measure, and examining new pressure injury records from 24 hours afterward until ICU discharge. The landmark analysis included patients who remained in the ICU at 24 hours after their first prone positioning and had no prior pressure injury records; the number of nursing documentation entries was transformed using ln (number + 1).

2.4. Statistical Methods

Statistical analyses were performed using R 4.2.3. Continuous variables with a normal distribution were expressed as mean and standard deviation, and group comparisons were conducted using independent-samples t-tests. Variables with a non-normal distribution were presented as median (M) and interquartile range (P25, P75), and group comparisons were analyzed using the Mann-Whitney U test. Categorical data were expressed as counts and percentages, and group comparisons were performed using χ^2 tests or Fisher's exact test. Multivariable logistic regression was used to examine the relationship between each variable measured before the index event and subsequent pressure injury records. Effect sizes were reported as odds ratios (OR) with 95% confidence intervals (CI), and model discrimination was evaluated using the C-statistic. A landmark logistic regression at 24 hours was employed to assess the association between the intensity of early prone positioning nursing documentation and subsequent pressure injury records. Two-sided tests were considered statistically significant at $P < 0.05$.

3. Results

3.1. Patient Screening and General Characteristics

Table 1. Pre-index characteristics stratified by post-index pressure injury documentation status

Categories	Total (N=297)	No new records added (n=195)	New records added (n=102)	*P*-value
Age (years)	60.00 (49.00,71.00)	60.00 (49.00,72.00)	60.00 (50.00,68.00)	0.710
Time from ICU admission to first prone position (hours)	30.67 (5.28,96.49)	30.00 (6.33,93.88)	34.11 (4.10,106.14)	0.731
Duration of invasive mechanical ventilation before prone positioning (hours)	20.50 (3.98,77.28)	22.67 (4.19,75.00)	17.35 (3.51,82.44)	0.653
Most recent Braden total score before prone positioning (points)	10.00 (9.00,12.00)	10.00 (9.00,12.00)	10.00 (9.00,11.00)	0.204
Number of recorded repositioning/position changes before prone positioning	11.00 (1.00,38.00)	11.00 (1.00,36.50)	10.50 (1.00,38.00)	0.996
Number of documented pressure-relief devices/protective dressings before prone positioning	11.00 (2.00,52.00)	10.00 (2.00,48.50)	13.00 (2.00,56.00)	0.611
Number of skin assessment records before prone positioning	10.00 (2.00,30.00)	10.00 (2.00,30.50)	10.00 (2.00,30.00)	0.810
Male [cases (%)]	182 (61.3)	114 (58.5)	68 (66.7)	0.168
Presence of at least one abnormal skin finding before prone positioning [cases (%)]	264 (88.9)	176 (90.3)	88 (86.3)	0.300

Note: ICU, Intensive care unit.

A total of 2,513 ICU patients with documented prone positioning were identified, of whom 968 had records of prone positioning during invasive mechanical ventilation. Further restricting to adult patients after their first ICU admission yielded a cohort of 735. After excluding 438 patients who already had pressure injury documentation before the first prone positioning, 297 patients were included in the final primary analysis cohort. Among these, 102 developed new pressure injuries after the initial prone positioning, resulting in an incidence of 34.34%.

The median age was 60.00 (49.00, 71.00) years, with 182 males (61.3%). The time from ICU admission to the first prone position was 30.67 (5.28, 96.49) hours, and the duration of invasive mechanical ventilation before prone positioning was 20.50 (3.98, 77.28) hours. The most recent Braden total score before prone positioning was 10.00 (9.00, 12.00). There were no statistically significant differences in baseline characteristics between the two groups (all $P > 0.05$), as shown in **Table 1**.

3.2. Pressure Injury Documentation Outcomes

As seen in **Figure 1,** among the 297 patients included, 102 (34.34%) had at least one new pressure injury documented after their first prone positioning (index event) during initial ICU admission, per the primary outcome definition. In a sensitivity analysis using the stricter outcome definition ("only clearly staged documentation"), 42 cases (14.14%) were identified. Further analyses setting minimum time intervals between the index event and the first pressure injury documentation to 6, 12, and 24 hours yielded estimated outcome proportions of 32.99%, 32.53%, and 30.40%, respectively. The rate gradually declined as the lag window increased (**Table 2**).

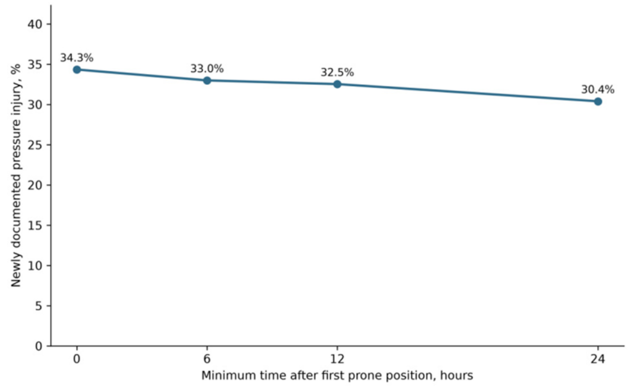

Figure 1. Estimated proportion of newly recorded pressure injuries under different minimum lag time windows after the first prone position

Note: 0 h indicates no minimum lag time; 6, 12, and 24 h indicate that only the first pressure injury record occurring at or after the respective time intervals following the index event is considered as the outcome.

Table 2. Pressure injury documentation rates across different outcome definitions and recording lag windows

Analysis Type	Time Threshold/h	Sample Size/n	Number of Events/n	Recording Rate/%	Effect Size
Primary outcome definition	0	297	102	34.34	—
Strict new site definition	0	297	42	14.14	—
Recording lag window	6	294	97	32.99	—
Recording lag window	12	292	95	32.53	—
Recording lag window	24	273	83	30.40	—
24-hour landmark analysis	24	255	83	32.55	OR=2.42 (1.39-4.19)*

Note: OR represents the odds ratio corresponding to the number of prone position recordings within 24 hours after the first prone positioning, transformed by ln (number + 1).

*P = 0.002.

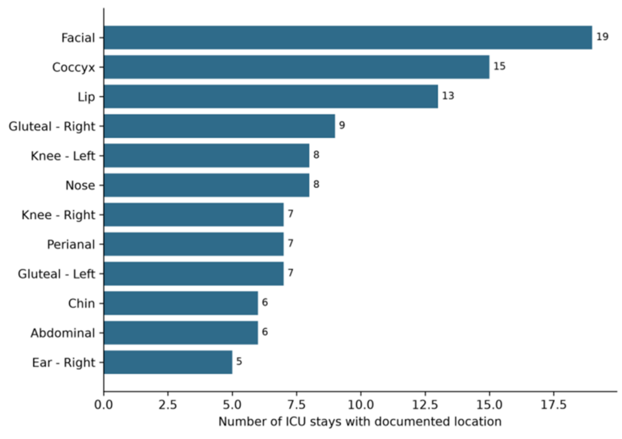

Figure 2. The 12 most frequently recorded body part categories for newly developed pressure injuries after initial prone positioning

Note: The x-axis represents the number of ICU admissions with records for the corresponding body parts; multiple body parts may be recorded for the same patient.

Among newly documented pressure injuries after prone positioning, the most frequently affected body regions were the face (19 cases), coccyx (15), lips (13), right buttock (9), and left knee and nose (8 each), followed by the right knee, perianal area, and left buttock (7 each). Fewer records were noted for the mandible, abdomen, and right ear (**Figure 2**). Body site information was aggregated according to the original chart categories in routine nursing documentation; these categories are not mutually exclusive, and multiple sites may be recorded per patient, so the sum of site frequencies may exceed the total number of pressure injury cases. These findings reflect the distribution of body sites in electronic nursing records and should not be interpreted as indicating a causal relationship between prone positioning and injury at specific anatomical locations.

3.3. Multivariate Analysis of Factors Related to Pressure Injury Documentation

A multivariable logistic regression model was developed using data from 297 patients, of whom 102 had new pressure injury documentation. The model's C-statistic was 0.594 and the Brier score was 0.219, which indicated limited discriminatory ability. Age, gender, most recent Braden total score prior to prone positioning, time from ICU admission to first prone position, duration of invasive mechanical ventilation before prone positioning, number of repositioning or position-change records, number of pressure-relief device or protective dressing records, and presence of abnormal skin findings were not statistically significant (all P > 0.05), as shown in **Table 3**.

Table 3. Multivariate logistic regression analysis of factors associated with new pressure injury documentation

Predictor	OR	95%CI	*P*-value
Age (per 1-year increase)	1.00	0.99-1.02	0.938
Male	1.56	0.92-2.63	0.096
Most recent Braden total score before prone positioning (per 1-point increase)	0.92	0.80-1.07	0.287
Time from ICU admission to first prone positioning (per 1-hour increase)	1.00	1.00-1.01	0.686
Duration of invasive mechanical ventilation before prone positioning (per 1-hour increase)	1.00	0.99-1.01	0.647
Number of recorded repositioning/position changes before prone positioning [ln (number + 1)]	0.68	0.41-1.15	0.151
Number of documented pressure-relief devices/protection dressings before prone positioning [ln (number + 1)]	1.45	0.89-2.37	0.132
Presence of abnormal skin before prone positioning	0.58	0.22-1.55	0.279

Note: OR: odds ratio; CI: confidence interval; ICU: intensive care unit.

The model C statistic was 0.594, and the Brier score was 0.219.

3.4. 24-Hour Boundary Analysis

A total of 255 patients who remained in the risk set at the 24-hour mark after initial prone positioning were included in the landmark analysis. Of these, 83 developed new pressure injury records after the landmark time, yielding a rate of 32.55%. The number of prone position documentation entries within 24 hours after initial prone positioning, when log-transformed, was significantly associated with subsequent new pressure injury documentation (OR = 2.42, 95% CI: 1.39–4.19, P = 0.002), as shown in **Table 2**. This result reflects a statistical association between nursing documentation intensity and subsequent pressure injury documentation, without implying causality.

4. Discussion

4.1. Pressure Injuries are Relatively Common in Adult ICU Patients Receiving Invasive Mechanical Ventilation after Prone Positioning.

This study analyzed 297 adult patients admitted to the ICU for the first time and receiving prone invasive mechanical ventilation, using the MIMIC-IV database. The results showed that 102 patients had new pressure injury records documented after their initial prone positioning, corresponding to a documentation rate of 34.34%. This figure falls within the range of cumulative incidence rates (25.7%–48.5%) reported by Patton et al. [2] for pressure injuries in adult ICU patients undergoing prone positioning, This suggests that pressure injuries related to prone positioning remain an important issue in critical care. Prone positioning redistributes body pressure, Areas such as the face, auricles, jaw, chest, iliac crests, and knees become primary pressure points. Endotracheal and nasogastric tubes, along with securing devices, create continuous localized pressure, which increases the risk of device-related pressure injuries [3].

However, this study evaluated newly documented pressure injury records from electronic medical records, rather than confirmed new-onset pressure injuries verified by wound specialists or imaging. When applying a stricter definition that requires pressure injuries to occur at previously unaffected sites (new site), the documentation rate decreased to 14.14%. When delayed documentation windows of 6, 12, and 24 hours were applied, the recorded rate also gradually declined. These findings suggest that some records documenting pressure injuries shortly after prone positioning may reflect delayed recognition or retrospective recording of pre-existing injuries. Therefore, the results of this study are better interpreted as reflecting documentation burden and monitoring needs, rather than direct clinical incidence rates.

4.2. Routine Baseline Nursing Variables Have Limited Discriminatory Ability for Newly Recorded Pressure Injuries

In this study, age, gender, pre-prone Braden total score, duration of mechanical ventilation before prone positioning, number of repositioning or position-change records, number of pressure-relief device or protective dressing records, and presence of abnormal skin were not significantly associated with documentation of new pressure injuries. The C-statistic of the main model was only 0.594, which means that routine nursing records prior to the index event alone are insufficient to identify patients at high risk for pressure injuries after prone positioning.

Previous studies have shown that the Braden scale has high sensitivity but low specificity in adult ICU patients, with considerable heterogeneity in its predictive performance[9, 10]. The median Braden score among patients in this study before prone positioning was 10, which means the overall population was already at relatively high risk. The relatively concentrated distribution of risk factors among participants may have limited the Braden scale's ability to further stratify patients. Domestic research has identified age, diabetes, duration of single-prone ventilation sessions, and sedation depth as risk factors for pressure injuries on the face associated with prone positioning[11]. This study did not fully capture variables such as cumulative prone time, duration of individual prone episodes, sedation depth, vasopressor dosage, tissue perfusion, nutritional status, and localized pressure from medical devices, which may explain the model's limited discriminatory power.

Pressure injuries associated with prone positioning also have context-specific characteristics. Traditional risk assessment tools emphasize mobility, moisture, nutrition, and friction/shear forces, whereas patients in the prone position are also affected by facial edema, prolonged continuous pressure, device-related immobilization, and skin invisibility[12]. Electronic health record studies have shown that incorporating disease severity, tissue perfusion, and dynamic nursing data into conventional scales can enhance the accuracy of pressure injury risk prediction[13, 14]. Therefore, clinicians should not rely solely on a single Braden score to determine preventive measures but should conduct dynamic assessments that integrate the duration of prone positioning, the interface between devices and skin, and hemodynamic status.

4.3. Early Prone Positioning Care Documentation Intensity is Associated with Subsequent Pressure Injury Documentation

The 24-hour landmark analysis showed that the number of prone-position records, log-transformed within the first 24 hours after initial prone positioning, was significantly associated with new pressure injury documentation after 24 hours (OR = 2.42, 95% CI: 1.39–4.19, P = 0.002). This finding suggests that the intensity of early prone-positioning nursing documentation may be an important signal for identifying subsequent risk of pressure injury.

Several explanations may account for this association. First, a higher number of documentation entries might reflect more frequent or prolonged prone-positioning therapy, which leads to greater cumulative pressure exposure. Second, patients with more severe illness, unstable oxygenation, or those requiring repeated prone positioning are typically under more intensive nursing surveillance, which may also increase their risk of pressure injuries[15]. Third, more frequent monitoring increases the likelihood of detecting and recording skin abnormalities, potentially introducing detection bias related to monitoring intensity. Nursing documentation in electronic health records reflects both clinical care practices and indirect indicators of patient complexity and nursing workload; it should not be simplistically interpreted as an independent causal factor[16]. This study employed a 24-hour landmark analysis, which to some extent ensures that exposure information precedes outcome documentation, yet it still cannot fully rule out unrecorded early injuries, residual confounding, or reverse causality. Therefore, the OR of 2.42 should not be interpreted as "more documentation leads to more pressure injuries," but rather as indicating that repeated or intensive prone-positioning documentation may signal the need for enhanced skin assessment and inspection of device-contact interfaces.

4.4. Implications for Clinical Nursing Practice

This study suggests that a dedicated pressure injury monitoring protocol should be established for patients undergoing prone invasive mechanical ventilation. Pressure on high-risk areas should be assessed every 2 hours during prone positioning, and protective measures should be evaluated for effectiveness[17]. Based on these requirements, clinical practice should focus on the following: completing a comprehensive skin assessment and evaluation of medical device contact sites prior to prone positioning; closely monitoring facial areas, auricles, lips, jaw, chest, iliac crests, knees, and toes during prone positioning; appropriately using preventive dressings and pressure-relieving support devices; regularly adjusting head and limb positions; and promptly reassessing and documenting skin condition after returning to supine position[18].

Nursing information systems should also incorporate structured data fields such as start and end times of prone positioning, cumulative duration, skin assessment sites, device contact interfaces, pressure-relief interventions, and post-supine skin status[19]. For patients with frequent documentation within 24 hours after initial prone positioning, nursing alerts can be set to trigger further skin assessments, rather than interpreting frequent documentation itself as an indicator of injury[20]. Standardizing recording terminology and assessment time points will improve data completeness and support the development of dynamic risk prediction models in the future.

4.5. Limitation

This study has several limitations. First, MIMIC-IV is a single-center retrospective database; patient characteristics, nursing procedures, and documentation practices may differ from those in domestic ICUs, so the external validity of the findings requires further validation. Second, pressure injury outcomes were primarily identified from nursing charts and related records, and recorded times do not necessarily correspond to the actual time of injury. Entries may be missing, delayed, or incorrectly stated. Third, the database lacks complete data on key variables such as cumulative prone positioning duration, sedation depth, exposure to vasopressors, nutritional status, tissue perfusion, and localized device pressure, making residual confounding unavoidable. Finally, the sample size is relatively small, no external validation was performed, and the C-statistic merely describes the discriminatory ability of existing variables—this model should not be used as a clinical prediction tool. Future multicenter prospective studies should incorporate structured nursing documentation, skin imaging, and dynamic physiological measurements to accurately determine the true timing of pressure injuries and validate the stability of associated factors.

5. Conclusion

New pressure injury documentation after the initial prone positioning in adult ICU patients receiving invasive mechanical ventilation is relatively common, and traditional baseline nursing variables are insufficient to identify high-risk patients. There is a significant association between the intensity of documentation of early prone positioning care and subsequent documentation of pressure injuries. Clinically, this should be a signal for more intensive skin monitoring, and should prompt the establishment of a continuous care assessment pathway covering the periods before prone positioning, during prone positioning, and after returning to the supine position.

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