Risk Factor Analysis and Optimal Modeling Method Selection for Facial Pressure Injuries Associated with Prone Ventilation: Postprint

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Date: 2023-08-30T00:00:00+00:00

Abstract

Background Facial pressure injury is a common complication in patients undergoing prone position ventilation. Local exposure of wounds can increase the risk of systemic infection, compromise the therapeutic efficacy of prone position ventilation, and even cause permanent functional damage to local tissues. Investigating its risk factors and constructing a predictive model holds important clinical significance for preventing prone position ventilation-related facial pressure injury. Objective To investigate the risk factors for prone position ventilation-related facial pressure injury and determine the optimal modeling approach. Methods A total of 159 patients who received prone position ventilation in the Department of Critical Care Medicine of the First Affiliated Hospital of Xinjiang Medical University from June 2020 to March 2023 were enrolled. Based on the occurrence of facial pressure injury, patients were divided into a pressure injury group (n=22) and a non-pressure injury group (n=137). General information, disease diagnosis, treatment measures, and laboratory test results were collected. Stepwise Logistic regression, full-variable Logistic regression, and Lasso-Logistic regression models were employed to screen risk factors for facial pressure injury and develop predictive models. The area under the receiver operating characteristic curve (AUC) was used to evaluate model discrimination; Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and calibration curves were used to assess model calibration; decision curve analysis was used to evaluate clinical utility. The optimal modeling method was selected by comparing predictive performance and clinical application differences among the three Logistic regression models. Results The stepwise Logistic regression model identified age (OR=39.041), diabetes (OR=7.256), and single-session prone position ventilation duration (OR=6.705) as influencing factors for facial pressure injury. The full-variable Logistic regression model identified age (OR=26.882), diabetes (OR=1.770), ICU length of stay (OR=2.610), and single-session prone position ventilation duration (OR=5.340) as influencing factors. The Lasso-Logistic regression model identified age (OR=38.256), diabetes (OR=1.094), single-session prone position ventilation duration (OR=5.738), and Richmond Agitation-Sedation Scale score (OR=1.179) as influencing factors. The Lasso-Logistic regression model for predicting prone position ventilation-related facial pressure injury achieved an AUC of 0.855, sensitivity of 0.959, and specificity of 0.750, which were superior to those of the stepwise and full-variable Logistic regression models. Its AIC and BIC were 44.634 and 55.745, respectively, which were lower than those of the stepwise and full-variable Logistic regression models. Calibration curves demonstrated that the Lasso-Logistic regression model had the best fit between predicted and actual probabilities. Decision curve analysis showed that the Lasso-Logistic regression model provided clinical benefit across risk thresholds of 0.01~0.98, outperforming the stepwise and full-variable Logistic regression models. Conclusion Age, diabetes, single-session prone position ventilation duration, and Richmond Agitation-Sedation Scale score are risk factors for prone position ventilation-related facial pressure injury. The Lasso-Logistic regression model demonstrates superior predictive performance and clinical utility compared with the stepwise Logistic regression model and full-variable Logistic regression model, representing the optimal modeling approach.

Full Text

Risk Factors of Prone Position Ventilation-related Facial Pressure Injuries and the Selection of Best Modeling Method

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Abstract

Background: Facial pressure injury is a common complication in patients undergoing prone position ventilation. Local exposure of wounds can increase the risk of systemic infection, compromise the therapeutic efficacy of prone position ventilation, and even cause permanent functional damage to local tissues. Identifying risk factors and constructing a prediction model are of great clinical significance for preventing prone position ventilation-related facial pressure injuries.

Objective: To investigate the risk factors for prone position ventilation-related facial pressure injuries and identify the optimal modeling approach.

Methods: A total of 159 patients admitted to the Department of Critical Care Medicine of the First Affiliated Hospital of Xinjiang Medical University between June 2020 and March 2023 who received prone position ventilation were enrolled. Patients were divided into a pressure injury group (n=22) and a non-pressure injury group (n=137) based on the occurrence of facial pressure injuries. General information, disease diagnosis, therapeutic measures, and laboratory test results were collected. Stepwise Logistic regression, full-variable Logistic regression, and Lasso-Logistic regression models were used to screen risk factors for facial pressure injuries and develop predictive models. The area under the receiver operating characteristic curve (AUC) was used to evaluate model discrimination. The Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and calibration curves were applied to assess model calibration. Decision curve analysis was used to evaluate the clinical utility of the models. The optimal modeling method was selected by comparing the predictive performance and clinical application value of the three Logistic regression models.

Results: The stepwise Logistic regression model identified age (OR=39.041), diabetes mellitus (OR=7.256), and duration of a single prone ventilation session (OR=6.705) as influencing factors for facial pressure injuries. The full-variable Logistic regression model identified age (OR=26.882), diabetes mellitus (OR=1.770), ICU length of stay (OR=2.610), and duration of a single prone ventilation session (OR=5.340) as influencing factors. The Lasso-Logistic regression model identified age (OR=38.256), diabetes mellitus (OR=1.094), duration of a single prone ventilation session (OR=5.738), and Richmond Agitation-Sedation Score (OR=1.179) as influencing factors. The Lasso-Logistic regression model achieved an AUC of 0.855, sensitivity of 0.959, and specificity of 0.750 for predicting prone position ventilation-related facial pressure injuries, which were superior to those of the stepwise and full-variable Logistic regression models. The AIC and BIC values were 44.634 and 55.745, respectively, which were lower than those of the other two models. Calibration curves demonstrated that the Lasso-Logistic regression model showed the best fit between predicted and actual probabilities. Decision curve analysis showed that the Lasso-Logistic regression model provided clinical benefit across a risk threshold range of 0.01–0.98, outperforming both the stepwise and full-variable Logistic regression models.

Conclusion: Age, diabetes mellitus, duration of a single prone ventilation session, and Richmond Agitation-Sedation Score are key risk factors for prone position ventilation-related facial pressure injuries. The Lasso-Logistic regression model demonstrates superior predictive performance and clinical utility compared to stepwise and full-variable Logistic regression models, making it the optimal modeling approach.

Keywords: Prone position ventilation; Pressure ulcer; Facial injuries; Risk factors; Lasso-logistic regression; Logistic models

Acute respiratory distress syndrome (ARDS) is characterized by progressive hypoxemia and respiratory distress as an acute hypoxic respiratory insufficiency or failure [1]. Prone position ventilation can effectively drain accumulated fluid from alveoli and improve oxygenation by altering intrathoracic pressure gradients [2]. Although this method can improve outcomes in ARDS patients to some extent, various complications may occur during prone position ventilation, affecting treatment efficacy and even causing permanent functional damage [3]. The risk of facial pressure injuries increases significantly in patients undergoing prone position ventilation, with studies showing that over 50% of intensive care unit (ICU) patients develop facial pressure injuries during prone position ventilation [4-5]. Screening for risk factors and implementing targeted preventive measures are crucial for reducing facial pressure injuries in these patients. However, current pressure injury risk assessment tools demonstrate poor predictive efficacy for facial pressure injuries and are difficult to apply clinically. Therefore, this study employed the Least Absolute Shrinkage and Selection Operator (Lasso) feature selection combined with Logistic regression to identify risk factors for facial pressure injuries in prone position ventilation patients and construct a prediction model. We compared the predictive performance of full-variable, stepwise, and Lasso-Logistic regression models to determine the optimal prediction model, evaluating both predictive efficacy and clinical application value to provide theoretical and practical basis for selecting appropriate risk assessment tools.

1.1 Study Subjects

A total of 159 patients admitted to the Department of Critical Care Medicine of the First Affiliated Hospital of Xinjiang Medical University between June 2020 and March 2023 who met the inclusion and exclusion criteria were enrolled after obtaining informed consent from family members or legal representatives. The cohort included 92 males and 67 females, with a mean age of (61.4\$$\pm$\$0.4) years and a median hospital stay of 13 days.

Inclusion criteria: (1) Age $\geq$ 18 years; (2) Acute Physiology and Chronic Health Evaluation II (APACHE II) score $\geq$ 8; (3) Patients receiving prone position ventilation.

Exclusion criteria: (1) Facial skin conditions affecting pressure injury assessment (e.g., facial burns); (2) Missing relevant indicators in electronic medical records.

Exclusion criteria during study: (1) Single prone ventilation session <0.5 hours or total prone ventilation time <4 hours.

1.2 Information Collection

Researchers developed a general information collection form based on study objectives and collected data through the hospital information system, intensive care information system, and laboratory information system. Data authenticity and accuracy were verified weekly by the researcher and another team member. General information included age, sex, and BMI. Disease diagnosis encompassed primary diagnosis, sepsis, and diabetes status. Treatment measures included total hospital stay, ICU length of stay, APACHE II score, Nutrition Risk Screening 2002 (NRS2002) score, Braden score, duration of single prone ventilation session, total prone ventilation time, mean arterial pressure (MAP), sedation status, Richmond Agitation-Sedation Score (RASS), mechanical ventilation mode, nutritional approach, continuous blood purification (CBP), intra-aortic balloon pump (IABP), and norepinephrine dosage. Laboratory indicators included oxygenation index (PaO2/FiO2), blood lactate, albumin, hemoglobin, and venous blood glucose.

1.3 Statistical Methods

Statistical analysis was performed using SPSS 20.0 and R 4.1.2 software. Normally distributed continuous data were expressed as ($\bar{x}\pm s$) and compared between groups using independent t-tests. Non-normally distributed continuous data were expressed as M(P25, P75) and compared using Mann-Whitney U tests. Categorical data were expressed as frequencies and compared using ^{2} tests or Fisher' s exact test. Variables with statistically significant differences in univariate analysis ($P<0.1$) were included in full-variable Logistic regression, stepwise Logistic regression, and Lasso-Logistic regression analyses to screen risk factors (αentry=0.05, αexit=0.1). Model discrimination was evaluated using the area under the receiver operating characteristic curve (AUC), sensitivity, and specificity, with AUC comparisons performed using Delong' s test. Model calibration was assessed using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and calibration curves. Decision curve analysis was used to determine clinical application value.

2.1 Patient General Data

All patients received preventive measures for facial pressure injuries during prone positioning (water bags placed under the face for pressure relief; pressure-relieving dressings applied to compressed skin; head position changed every 2 hours, etc.). Pressure injury diagnosis was based on the 2016 Pressure Injury Staging System from the National Pressure Ulcer Advisory Panel (NPUAP) [6]. Patients were divided into pressure injury and non-pressure injury groups based on whether facial pressure injuries occurred at the time of transfer, discharge, or death. This study was approved by the Medical Ethics Committee of the First Affiliated Hospital of Xinjiang Medical University.

Among the 159 patients, 22 developed facial pressure injuries, yielding an incidence rate of 13.8%. Injuries occurred at the oral region in 12 cases, zygomatic region in 6 cases, and mandibular region in 4 cases. Significant differences between the pressure injury and non-pressure injury groups were observed in age, diabetes mellitus proportion, ICU length of stay, duration of single prone ventilation session, total prone ventilation time, RASS, mechanical ventilation mode, continuous blood purification treatment proportion, IABP treatment proportion, norepinephrine dosage, PaO2/FiO2, and blood lactate ($P<0.1$). No significant differences were found in sex, BMI, primary diagnosis, sepsis proportion, total hospital stay, APACHE II score, NRS2002 score, Braden score, mean arterial pressure, sedation proportion, nutritional approach, albumin, hemoglobin, or venous blood glucose ($P>0.1$) .

2.2 Influencing Factors for Prone Position Ventilation-related Facial Pressure Injuries

The occurrence of facial pressure injury (assignment: no=0, yes=1) served as the dependent variable. Variables with statistically significant differences in univariate analysis ($P<0.1$) were included as independent variables in Logistic regression models: age, ICU length of stay, duration of single prone ventilation session, total prone ventilation time, RASS, norepinephrine dosage, PaO2/FiO2, blood lactate (assigned as actual measured values); diabetes mellitus, invasive mechanical ventilation, high-flow nasal cannula oxygen therapy, blood purification treatment, IABP treatment (assignment: no=0, yes=1).

Figure 1 [Figure 1: see original paper] illustrates the Lasso feature selection process. When $\lambda=0.00244371$, four variables with non-zero coefficients were selected: age, diabetes mellitus, duration of single prone ventilation session, and RASS. Stepwise Logistic regression, full-variable Logistic regression, and Lasso-Logistic regression models were used to identify influencing factors. The stepwise Logistic regression model showed that influencing factors were age (OR=39.041), diabetes mellitus (OR=7.256), and duration of single prone ventilation session (OR=6.705). The full-variable Logistic regression model showed influencing factors of age (OR=26.882), diabetes mellitus (OR=1.770), ICU length of stay (OR=2.610), and duration of single prone ventilation session (OR=5.340). The Lasso-Logistic regression model showed influencing factors of age (OR=38.256), diabetes mellitus (OR=1.094), duration of single prone ventilation session (OR=5.738), and RASS (OR=1.179) .

2.3.1 Model Predictive Efficacy

The three Logistic regression models were constructed as follows:

Stepwise Logistic regression model:
$P = 1/[1 + e\hat{}(-X)]$, where $X = -1.392 + 2.506\times$age $+ 1.982\times$diabetes mellitus $+ 1.193\times$duration of single prone ventilation session

Full-variable Logistic regression model:
$P = 1/[1 + e\hat{}(-X)]$, where $X = -1.941 + 1.633\times$age $+ 0.189\times$diabetes mellitus $+ 0.248\times$ICU length of stay $+ 0.609\times$duration of single prone ventilation session

Lasso-Logistic regression model:
$P = 1/[1 + e\hat{}(-X)]$, where $X = -1.099 + 5.021\times$age $+ 0.146\times$diabetes mellitus $+ 1.984\times$duration of single prone ventilation session $+ 0.150\times$RASS

Comparison of AUC, sensitivity, and specificity among the three models revealed that the Lasso-Logistic regression model' s AUC was significantly higher than both the stepwise Logistic regression model (Z=2.417, P=0.015) and the full-variable Logistic regression model (Z=2.8342, P=0.004). Additionally, this model demonstrated superior sensitivity and specificity compared to the other two Logistic regression models, indicating good discrimination. Figure 2 [Figure 2: see original paper] presents the calibration curves for the three models. The diagonal line represents perfect agreement between predicted and actual probabilities under ideal conditions. The colored curves show the consistency between model-predicted risk event probabilities and actual occurrence probabilities; curves closer to the diagonal indicate better fit. The calibration curves demonstrated that the Lasso-Logistic regression model showed the best agreement between predicted and actual probabilities, while the stepwise and full-variable Logistic regression models exhibited some degree of deviation. Among the three models, the Lasso-Logistic regression model had the highest R^2 and the lowest AIC and BIC values, further confirming its superior fit .

2.3.2 Model Clinical Application Value

Decision curves illustrate the clinical net benefit of identifying all patients as pressure injury patients versus non-pressure injury patients (represented by the gray diagonal and black horizontal lines in Figure 3 [Figure 3: see original paper]) and the actual clinical benefit of each model. The larger the range of risk thresholds where the model's decision curve intersects with the gray diagonal and black horizontal lines, the higher the model' s practical application value. The stepwise and full-variable Logistic regression models provided clinical benefit across risk threshold ranges of 0.01–0.83 and 0.01–0.85, respectively, while the Lasso-Logistic regression model provided clinical benefit across a risk threshold range of 0.01–0.98. These results collectively indicate that the Lasso-Logistic regression model offers higher clinical application value.

Discussion

In this study, the stepwise Logistic regression analysis identified three risk factors for facial pressure injuries, while the full-variable and Lasso-Logistic regression analyses each identified four risk factors. Age, diabetes mellitus, and duration of single prone ventilation session were consistently selected as risk factors across all three Logistic regression analyses. International studies have demonstrated that duration of single prone ventilation session and total prone ventilation time are the most direct risk factors for pressure injuries [7]. Patients undergoing prone position ventilation experience facial skin and subcutaneous tissue edema due to gravitational effects. Additionally, saliva in the oral cavity, accumulated oral secretions from airways, and reflux of gastric contents keep facial skin in a prolonged moist state. The interaction between digestive enzymes and bacteria damages the skin barrier, thereby increasing pressure injury risk [8-10]. Our results showed that patients with pressure injuries had significantly longer single prone ventilation sessions and total prone ventilation times compared to those without injuries, but only duration of single prone ventilation session showed significant association with facial pressure injuries. Although prone positioning can improve ventilation/perfusion ratio in a short time, alveolar recruitment and fluid drainage require longer durations. Therefore, prolonged prone position ventilation (>12 hours or >16 hours) is needed to significantly improve patient outcomes [11-12]. In clinical practice, some patients have poor tolerance to prone position ventilation. For these patients, a segmented prone ventilation strategy is adopted (prone position for 2-4 hours, rest for 1-2 hours, then prone position again for 2-4 hours). This segmented approach shortens local tissue compression time, but the total prone ventilation time is comparable to continuous prone ventilation. Consequently, total prone ventilation time was not significantly associated with facial pressure injuries in this study.

This study found that age is an important influencing factor for facial pressure injuries in prone position ventilation patients. PACHÁ et al. [13] found that compared with patients aged \$ \$40 years, patients aged 61-80 years and >80 years had 2.6 times [OR=2.6, 95%CI (1.2, 5.6), P=0.01] and 3.7 times [OR=3.7, 95%CI (1.4, 9.7), P<0.001] higher risk of pressure injuries, respectively. Meta-analyses have shown that diabetic patients have significantly higher risk of pressure injuries than non-diabetic patients [14-15]. In this study, diabetic patients undergoing prone position ventilation were more likely to develop facial pressure injuries, although blood glucose levels did not differ significantly between patients with and without pressure injuries, suggesting that chronic hyperglycemia may increase tissue damage risk. Under normal conditions, local capillary dilation increases tissue perfusion after compression, but elderly and diabetic patients have impaired capillary-mediated local blood flow regulation, making them more susceptible to pressure injuries [16]. Furthermore, in the Lasso-Logistic regression model with the highest predictive efficacy, RASS was also closely associated with facial pressure injury risk, consistent with KOO et al.' s findings [17]. Moderate to deep sedation (RASS<-3) helps reduce patient respiratory effort and patient-ventilator asynchrony, enabling tolerance of longer prone positioning sessions [18]. However, deep sedation reduces patient perception of pain and other noxious stimuli, which may contribute to increased pressure injury risk [19].

Lasso regression, first proposed by Robert Tibshirani in 1996, adds the sum of absolute values of all variable regression coefficients as a penalty term to the least squares method, compressing coefficients of independent variables not significantly associated with the dependent variable to zero, thereby selecting variables with stronger correlations [20]. Multiple studies have confirmed that Lasso-Logistic regression models demonstrate superior predictive efficacy compared to stepwise and full-variable Logistic regression models [21-25]. This study used stepwise Logistic regression, full-variable Logistic regression, and Lasso-Logistic regression to identify risk factors for facial pressure injuries. All three models showed high sensitivity, but the Lasso-Logistic regression model exhibited significantly higher specificity. The Lasso-Logistic model demonstrated better fit between predicted and observed values than the stepwise and full-variable models, indicating superior predictive performance. In terms of clinical application value, the net benefit of the stepwise and full-variable Logistic regression models showed no significant difference, while the Lasso-Logistic regression model demonstrated higher net benefit and clinical application value. These results collectively indicate that the Lasso-Logistic regression model is the optimal model for predicting facial pressure injuries in prone position ventilation patients and may represent the currently ideal modeling approach.

This study identified age, diabetes mellitus, duration of single prone ventilation session, and Richmond Agitation-Sedation Score as key risk factors for prone position ventilation-related facial pressure injuries based on the Lasso-Logistic regression model. Clinical nurses can use this model to predict facial pressure injury risk and identify high-risk patients based on these risk factors. Additionally, these findings provide theoretical and decision-making basis for improving prone position ventilation strategies and reducing related complications, thereby helping to decrease the incidence of facial pressure injuries in prone position ventilation patients. However, this study has several limitations, including its single-center design and relatively small sample size. Furthermore, univariate analysis paid insufficient attention to local factors such as moisture and edema. Therefore, larger sample sizes and inclusion of more potential variables are needed to more comprehensively explore risk factors for facial pressure injuries in prone position ventilation patients and provide clinical nurses with risk prediction tools of higher predictive accuracy and application value.

Conclusion: Age, diabetes mellitus, duration of single prone ventilation session, and Richmond Agitation-Sedation Score are key risk factors for prone position ventilation-related facial pressure injuries. The Lasso-Logistic regression model demonstrates superior predictive performance and clinical application value compared to stepwise and full-variable Logistic regression models, making it the optimal modeling approach for facial pressure injury prediction models.

Author Contributions: YUAN Yuan was responsible for study design, manuscript drafting, and data collection. ZHANG Yarong participated in data collection. LI Zhengang contributed to data collection and statistical analysis. ZHANG Li was responsible for research conceptualization, proposition, and design.

Conflict of Interest: The authors declare no conflict of interest.

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(Received: 2023-04-15; Revised: 2023-07-12)

Note: Figure translations are in progress. See original paper for figures.