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Evaluation of Respiratory Mechanics and Endotracheal Tube Dynamics during Prone Positioning under General Anaesthesia: A Prospective Observational Study

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ABSTRACT

Introduction: Prone positioning is essential for various surgical procedures, including spinal surgeries, posterior cranial fossa procedures and urological interventions, as it provides optimal access to posterior anatomical structures. However, this positioning significantly alters respiratory mechanics and cardiovascular physiology, potentially affecting patient safety during general anaesthesia. Peak Airway Pressure (PAP) and Endotracheal Tube (ETT) cuff pressure are critical parameters that require careful monitoring during prone positioning to prevent complications such as barotrauma and tracheal injury.

Aim: To evaluate simultaneous changes in PAP and ETT cuff pressure during prone positioning under general anaesthesia and to assess associated haemodynamic alterations.

Materials and Methods: This prospective observational study was conducted at Department of Anaesthesiology and Critical Care, Adesh Institute of Medical Sciences and Research, Adesh University, Bathinda, Punjab, India. The study enrolled 105 consecutive American Society of Anaesthesiologists (ASA) I-II patients scheduled for elective procedures requiring prone positioning. Standardised protocols were used to document PAP, ETT cuff pressure and haemodynamic variables at multiple time points: baseline in the supine position, immediately after prone positioning and at 15-minute intervals throughout the procedure. Statistical analysis employed paired comparisons, with a significance threshold of p-value <0.05.

Results: A total of 105 patients completed the study (mean age 45.36±10.26 years; 62.9% female; mean Body Mass Index (BMI) 21.41±2.56 kg/m^2). Transitioning from supine to prone position produced significant respiratory mechanical alterations. Baseline supine PAP (19.03±3.35 cm H_2O) progressively increased to a maximum of 34.36±2.59 cm H_2O during prone maintenance (p-value <0.001), representing an 80.6% elevation. Similarly, ETT cuff pressure increased from baseline (24.64±2.99 cm H_2O) to 43.65±4.49 cm H_2O at maximum prone measurement (p-value <0.001). Cardiovascular parameters demonstrated significant alterations during the initial 15 minutes post-positioning before stabilising during the maintenance phase.

Conclusion: In patients under general anaesthesia, the prone position significantly increases PAP and ETT cuff pressure. This finding underscores the importance of regular monitoring and timely interventions to limit the risks associated with elevated pressures.

Keywords: Airway management, Haemodynamics, Intraoperative, Monitoring, Operative, Pressure, Surgery

INTRODUCTION

Proper positioning of patients during surgery is fundamental in achieving optimal access to surgical procedures, minimising physiological disturbances, preventing position-related complications and providing maximum comfort. The prone position is often used for procedures that manipulate posterior anatomical structures, such as spine surgeries, posterior cranial fossa procedures and certain urological procedures, notably Percutaneous Nephrolithotomy (PCNL). The prone position allows excellent access but poses multiple anaesthetic challenges. It has physiological effects, including changes in cardiovascular and respiratory parameters. Data on physiologic shifts in cardiac output, blood pressure and pulmonary compliance when patients are placed prone from the supine position under general anaesthesia have been published [1,2].

PAP, a measure of the forces applied to the lungs during inflation, is one such parameter commonly monitored during mechanical ventilation. Normal PAP is 25-30 cmH_2O; values above 40 cmH_2O can be dangerous and cause barotrauma [3]. PAP may increase in the prone position due to decreased chest wall compliance and changes in respiratory mechanics. ETT cuff pressure also needs to be monitored closely during position changes. The ideal cuff pressure for the ETT has been reported to be between 20-30 cmH_2O, as pressures lower than this can lead to aspiration and ventilator-associated pneumonia, while higher pressures can impair tracheal mucosal perfusion causing ischaemic injury [4,5].

Although these physiological changes are well documented individually [1,2,6,7], data on the simultaneous measurement of PAP and ETT cuff pressure variation during prone positioning are limited [8,9]. Most previous studies have focused on either respiratory mechanics or haemodynamic changes separately, rather than on comprehensive monitoring of both airway and cuff pressures throughout the prone-positioning period [6,8-12].

General anaesthetic agents affect respiratory mechanics and knowledge of these changes can help anaesthesiologists optimise ventilatory settings, minimise complications from elevated airway and cuff pressures and keep patients safe during procedures requiring prone positioning. Given the limited data on simultaneous monitoring of both parameters during prone positioning, this study aimed to prospectively evaluate changes in PAP and ETT cuff pressure when patients are turned from supine to prone position under general anaesthesia, while also monitoring associated haemodynamic alterations throughout the procedure [13-15]. This prospective observational study was designed to evaluate, for the first time, the simultaneous changes in PAP and ETT cuff pressure following the transition from supine to prone position and during maintenance of prone positioning throughout general anaesthesia.

MATERIALS AND METHODS

This prospective observational study was conducted in the Department of Anaesthesiology and Critical Care at Adesh Institute of Medical Sciences and Research, Adesh University, Bathinda, from January to June 2024. The institutional review board approved this protocol (Ref. No AIMSR/MC/Estt/1287), and all participants provided written informed consent prior to enrolment.

Inclusion criteria: Adult patients aged 18-65 years, ASA physical status I-II, scheduled for elective procedures requiring prone positioning under general anaesthesia were included in the study.

Exclusion criteria: Patients with anatomical abnormalities contraindicating prone positioning, those with uncompensated cardiopulmonary disease, patients with a documented history of substance use disorders, those who had received general anaesthesia within the preceding seven days and patients with body mass index exceeding 35 kg/m² were excluded from the study.

Sample size: Sample size calculation, using a priori power analysis with a significance threshold (α) of 0.05, desired power ($1-\beta$) of 0.95, and anticipated effect size of 0.35 for the primary outcome measure, indicated a minimum of 95 participants, increased to 105 to accommodate potential attrition.

A total of 105 patients met the inclusion criteria and were enrolled in the study. All enrolled patients completed the study protocol without deviation.

Study Procedure

All participants underwent standardised preoperative evaluation, including comprehensive history, physical examination and laboratory assessment. Premedication consisted of oral alprazolam 0.25 mg and ranitidine 150 mg administered the evening before surgery.

Upon arrival at the operating suite, standard monitoring including five-lead electrocardiography, non invasive oscillometric blood pressure measurement, pulse oximetry and capnography was established. Following preoxygenation to end-tidal oxygen concentration exceeding 80%, anaesthesia induction proceeded with intravenous administration of midazolam (0.03-0.05 mg/kg), fentanyl (1-2 mcg/kg), and propofol (1.5-2.5 mg/kg) titrated to loss of consciousness.

Neuromuscular blockade with vecuronium (0.1 mg/kg) facilitated endotracheal intubation using appropriately sized tubes (internal diameter 7.0-7.5 mm for female participants and 8.0-8.5 mm for male participants). Initial ETT cuff inflation employed 4 mL of ambient air with subsequent adjustment to obtain minimal occlusive volume. Anaesthesia maintenance consisted of an oxygen-nitrous oxide mixture (FiO_2 0.4-0.5) with isoflurane (0.8-1.2 MAC) delivered through a circle breathing system.

Positioning Protocol and Measurement Technique

Standardised prone positioning protocol: All prone positioning procedures followed a standardised four-person team protocol: anaesthesiologist managing head/airway, surgeon supervising the torso, and two assistants managing the extremities. The positioning sequence included turning as a single unit, the head maintained in neutral alignment using a foam headrest, the chest supported with a Wilson frame allowing free abdominal movement, arms positioned at the sides or in the Superman configuration and pressure points padded. PAP, ETT cuff pressure, heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, oxygen saturation, and end-tidal CO_2 were continuously monitored and recorded at predetermined intervals throughout the procedure.

Interobserver reliability was assessed in 25 patients (23.8%) with duplicate measurements. Intraclass correlation coefficients demonstrated excellent agreement: PAP (ICC=0.94, 95% CI: 0.89-0.97) and ETT cuff pressure (ICC=0.91, 95% CI: 0.85-0.95). All equipment underwent monthly calibration.

STATISTICAL ANALYSIS

Statistical Package for the Social Sciences (SPSS) software (version 27.0, IBM Corporation, Armonk, NY) and GraphPad Prism (version 5.0, GraphPad Software, San Diego, CA) for analysis. Descriptive statistics characterised demographic and clinical variables (mean±standard deviation for normally distributed continuous variables; median with interquartile range for non normally distributed continuous variables; and frequencies with percentages for categorical variables). Normality was assessed using the Shapiro-Wilk test. For comparative analyses, paired t-tests to evaluate within-subject changes in continuous variables between measurement time points, using baseline supine values as the reference. Ninety-five percent confidence intervals (95% CIs) were calculated for all mean differences and reported alongside point estimates. Effect sizes were calculated using Cohen's d for paired comparisons, with values interpreted as small (0.2), medium (0.5), and large (0.8) effects. For multiple time-point comparisons, Bonferroni correction was applied to control for Type I error inflation. The significance threshold was adjusted from α=0.05 to α=0.05/9=0.0056 for the nine prone-positioning time points (T1, T15, T30, T45, T60, T75, T90, T105, T120). Both uncorrected and Bonferroni-corrected p-values are reported in the results. Correlation analyses were performed to assess the relationship between changes in PAP and ETT cuff pressure during prone positioning. Pearson correlation coefficients were calculated for pressure changes from baseline, with 95% CIs reported. Clinical significance thresholds were defined as PAP >40 cmH_2O (barotrauma risk) [16,17] and ETT cuff pressure >30 cmH_2O (exceeding safety recommendations) [18,19]. Analysis included the proportion of patients exceeding thresholds, time to exceedance, and predictive factors using multivariable logistic regression.

RESULTS

The study population was predominantly female with an age distribution centered on middle age, indicating good demographic representativeness for surgical procedures requiring prone positioning. Anthropometric characteristics demonstrated a healthy study cohort, with the majority having a normal BMI and an equal distribution between ASA I and II classifications, ensuring appropriate risk stratification for the study objectives. Comprehensive demographic data are summarised in [Table/Fig-1].

Variable	Value
Age (years), mean±SD	45.36±10.26
Age distribution, n (%) (years)	
20-30	6 (5.7)
31-40	29 (27.6)
41-50	36 (34.3)
51-60	24 (22.9)
>60	10 (9.5)
Gender, n (%)	
Male	39 (37.1)
Female	66 (62.9)
Weight (kg), mean±SD	59.35±6.85
BMI (kg/m²), mean±SD	21.41±2.56
BMI classification, n (%)	
Underweight	9 (8.6)
Normal	90 (85.7)
Overweight	6 (5.7)
ASA Classification, n (%)	
ASA I	49 (46.7)
ASA II	56 (53.3)

[Table/Fig-1]: Demographic characteristics of study population.

Haemodynamic parameters: Showed significant changes immediately after turning patients to the prone position [Table/Fig-2]. The initial 15 minutes post-positioning demonstrated the most pronounced alterations, with subsequent stabilisation during the maintenance phase, indicating that cardiovascular adaptation to prone positioning occurs relatively quickly after the initial transition period. When patients were returned to the supine position at the end of surgery (TSE), all haemodynamic parameters were significantly higher than baseline, likely reflecting emergence from anaesthesia.

Peak Airway Pressure (PAP): PAP showed highly significant changes between supine and prone positions [Table/Fig-3]. Progressive increases were observed throughout prone positioning, with the most dramatic elevation occurring after the initial 30 minutes, indicating that respiratory mechanics continue to deteriorate with prolonged prone positioning rather than stabilising after the initial position change.

When comparing PAP at the beginning of anaesthesia in the supine position (TS) with PAP at the end of surgery in the supine position (TSE), no significant difference was observed (19.03±3.35 vs 20.28±5.30 cmH_2O, p-value=0.065), indicating that the changes were primarily related to positioning rather than prolonged mechanical ventilation [Table/Fig-4].

Endotracheal Tube (ETT) cuff pressure: ETT cuff pressure demonstrated significant elevations during prone positioning [Table/Fig-5]. The pressure increased progressively throughout prone positioning, with the most substantial rise occurring within the first 30 minutes, reaching clinically concerning levels that exceeded safety thresholds.

Parameter	Time point	Mean±SD	95% CI	Mean difference from baseline	95% CI of difference	p-value†	p-value‡
Heart rate (bpm)	Supine TS	82.44±10.43	80.42-84.46	reference	-	-	-
	Prone T1	80.05±9.49	78.22-81.88	-2.39	-4.22 to -0.56	0.027	0.243
	Prone T15	78.85±10.63	76.79-80.91	-3.59	-5.65 to -1.53	0.003	0.027
	Prone T30	84.10±8.65	82.42-85.78	1.66	-0.02 to 3.34	0.074	0.666
	Prone T45	81.47±8.21	79.88-83.06	-0.97	-2.56 to 0.62	0.341	1.000
	Prone T60	81.42±8.19	79.84-83.00	-1.02	-2.60 to 0.56	0.353	1.000
	Prone T90	81.80±8.77	80.10-83.50	-0.64	-2.34 to 1.06	0.626	1.000
	Supine TSE	81.46±8.49	79.81-83.11	-0.98	-2.63 to 0.67	0.409	1.000
Systolic BP (mmHg)	Supine TS	124.26±9.50	122.42-126.10	reference	-	-	-
	Prone T1	129.30±11.91	126.99-131.61	5.04	2.73-7.35	0.001	0.009*
	Prone T15	127.08±10.14	125.12-129.04	2.82	0.86-4.78	0.033	0.297
	Prone T30	123.50±10.51	121.46-125.54	-0.76	-2.80 to 1.28	0.561	1.000
	Prone T45	126.22±10.16	124.25-128.19	1.96	-0.01 to 3.93	0.120	1.000
	Prone T60	124.47±12.03	122.14-126.80	0.21	-2.12 to 2.54	0.876	1.000
	Prone T90	123.28±10.27	121.29-125.27	-0.98	-2.97 to 1.01	0.488	1.000
	Supine TSE	139.57±12.84	137.08-142.06	15.31	12.82-17.80	<0.001	<0.0056*
Diastolic BP (mmHg)	Supine TS	76.79±6.15	75.60-77.98	reference	-	-	-
	Prone T1	80.20±11.17	78.03-82.37	3.41	1.24-5.58	0.001	0.009*
	Prone T15	81.19±8.35	79.57-82.81	4.40	2.78-6.02	<0.001	<0.0056*
	Prone T30	78.81±10.78	76.72-80.90	2.02	-0.07 to 4.11	0.083	0.747
	Prone T45	76.99±10.57	74.94-79.04	0.20	-1.85 to 2.25	0.864	1.000
	Prone T60	78.57±8.01	77.01-80.13	1.78	0.22-3.34	0.074	0.666
	Prone T90	77.91±8.60	76.24-79.58	1.12	-0.55 to 2.79	0.241	1.000
	Supine TSE	90.07±9.74	88.18-91.96	13.28	11.39-15.17	<0.001	<0.0056*
Mean Arterial Pressure (mmHg)	Supine TS	92.68±6.34	91.45-93.91	reference	-	-	-
	Prone T1	95.20±10.78	93.11-97.29	2.52	0.43-4.61	0.035	0.315
	Prone T15	96.27±7.78	94.76-97.78	3.59	2.08-5.10	<0.001	<0.0056*
	Prone T30	93.54±9.12	91.77-95.31	0.86	-0.91 to 2.63	0.391	1.000
	Prone T45	93.26±8.60	91.59-94.93	0.58	-1.09 to 2.25	0.564	1.000
	Prone T60	93.53±10.92	91.41-95.65	0.85	-1.27 to 2.97	0.484	1.000
	Prone T90	93.59±7.64	92.11-95.07	0.91	-0.57 to 2.39	0.340	1.000
	Supine TSE	106.25±9.66	104.38-108.12	13.57	11.70-15.44	<0.001	<0.0056*

[Table/Fig-2]: Comparison of haemodynamic parameters between supine and prone position at different time intervals.
Data normality were assessed using the Shapiro-Wilk test; paired t-tests were applied for normally distributed parameters with SUPINE TS as reference; †Uncorrected p-values from paired t-test
‡Bonferroni-corrected p-values (α=0.0056) *Statistically significant after Bonferroni correction TS: Baseline in supine position; T1, T15, T30, T45, T60, T90: Time points in minutes after prone positioning; TSE: After returning to supine position at the end of surgery; BP: Blood pressure

Time point	Prone PAP (cmH_2O)	95% CI	Supine TS (cmH_2O)	Mean difference	95% CI of difference	Cohen's d	p-value†	p-value‡
T1	20.74±3.33	20.09-21.39	19.03±3.35	1.71	1.17-2.25	0.51	<0.001	<0.0056*
T15	22.34±4.50	21.47-23.21	19.03±3.35	3.31	2.44-4.18	0.82	<0.001	<0.0056*
T30	32.76±3.59	32.06-33.46	19.03±3.35	13.73	12.75-14.71	3.94	<0.001	<0.0056*
T45	33.01±3.05	32.42-33.60	19.03±3.35	13.98	13.09-14.87	4.35	<0.001	<0.0056*
T60	33.15±3.28	32.51-33.79	19.03±3.35	14.12	13.25-14.99	4.26	<0.001	<0.0056*
T75	33.87±2.79	33.33-34.41	19.03±3.35	14.84	14.01-15.67	4.74	<0.001	<0.0056*

T90	33.60±2.73	33.07-34.13	19.03±3.35	14.57	13.75-15.39	4.67	<0.001	<0.0056*
T105	34.36±2.59	33.86-34.86	19.03±3.35	15.33	14.53-16.13	5.04	<0.001	<0.0056*
T120	33.65±3.41	32.99-34.31	19.03±3.35	14.62	13.73-15.51	4.38	<0.001	<0.0056*

[Table/Fig-3]: Comparison of Peak Airway Pressure (PAP) between supine and prone position at different time intervals.
Shapiro-Wilk test confirmed normal distribution (p>0.05) for all time points; paired t-tests were applied accordingly. Statistically significant results are indicated where p<0.05; †Uncorrected p-values from paired t-test ‡Bonferroni-corrected p-values (α=0.0056) *Statistically significant after Bonferroni correction TS: Baseline in supine position; T1-T120: Time points in minutes after prone positioning Cohen's d interpretation: 0.2=small effect, 0.5=medium effect, 0.8=large effect

Parameter	N	Mean±SD	95%CI	95% CI of difference	t-value	p-value
PAP Supine (TS)	105	19.03±3.35	18.38-19.68	-0.03 to 2.53	1.864	0.065
PAP Supine (TSE)	105	20.28±5.30	19.26-21.30	-	-	-

[Table/Fig-4]: Comparison of Peak Airway Pressure (PAP) between supine position at beginning and end of surgery.
TS: Baseline in supine position; TSE: After returning to supine position at end of surgery No significant difference between beginning and end PAP values in supine position

Time point	Prone ETT cuff pressure (cmH_2O)	95% CI	Supine TS (cmH_2O)	Mean difference	95% CI of difference	Cohen's d	p-value†	p-value‡
T1	26.21±3.01	25.63-26.79	24.64±2.99	1.57	1.02-2.12	0.52	<0.001	<0.0056*
T15	34.00±8.89	32.28-35.72	24.64±2.99	9.36	7.64-11.08	1.35	<0.001	<0.0056*
T30	42.84±4.20	42.03-43.65	24.64±2.99	18.20	17.39-19.01	5.05	<0.001	<0.0056*
T45	43.27±4.06	42.48-44.06	24.64±2.99	18.63	17.84-19.42	5.26	<0.001	<0.0056*
T60	43.38±4.62	42.49-44.27	24.64±2.99	18.74	17.85-19.63	4.85	<0.001	<0.0056*
T75	43.65±4.49	42.78-44.52	24.64±2.99	19.01	18.14-19.88	4.99	<0.001	<0.0056*
T90	42.68±3.42	42.02-43.34	24.64±2.99	18.04	17.38-18.70	5.87	<0.001	<0.0056*
T105	42.99±3.87	42.24-43.74	24.64±2.99	18.35	17.60-19.10	5.41	<0.001	<0.0056*
T120	41.93±3.28	41.30-42.56	24.64±2.99	17.29	16.66-17.92	5.64	<0.001	<0.0056*

[Table/Fig-5]: Comparison of Endotracheal Tube (ETT) cuff pressure between supine and prone position at different time intervals.
Normality verified using Shapiro-Wilk test prior to statistical analysis; paired t-test used for comparisons; †Uncorrected p-values from paired t-test ‡Bonferroni-corrected p-values (α=0.0056) *Statistically significant after Bonferroni correction TS: Baseline in supine position; T1-T120: Time points in minutes after prone positioning Cohen's d interpretation: 0.2=small effect, 0.5=medium effect, 0.8=large effect

Correlation between Peak Airway Pressure (PAP) and ETT cuff pressure: A strong positive correlation was observed between changes in PAP and ETT cuff pressure during prone positioning [Table/Fig-6]. This relationship remained consistent throughout all measurement time points. The overall correlation coefficient across all time points was r=0.687 (95% CI: 0.612-0.748, p-value <0.001), indicating that patients experiencing greater increases in PAP also demonstrated proportionally greater elevations in ETT cuff pressure. The correlation remained consistently strong throughout the prone positioning period, ranging from r=0.654 at T15 to r=0.723 at T30. This sustained relationship suggests shared physiological mechanisms underlying both pressure changes during prone positioning, likely related to increased intrathoracic pressure transmission affecting both airway resistance and tracheal compression.

Time point	Correlation coefficient (r)	95% CI	p-value	Correlation strength	R^2 (Variance explained)
T15	0.654	0.572-0.724	<0.001	Strong	42.8%
T30	0.723	0.654-0.783	<0.001	Strong	52.3%
T45	0.701	0.628-0.764	<0.001	Strong	49.1%
T60	0.695	0.621-0.759	<0.001	Strong	48.3%
T75	0.682	0.606-0.747	<0.001	Strong	46.5%
T90	0.678	0.601-0.744	<0.001	Strong	46.0%
T105	0.671	0.592-0.738	<0.001	Strong	45.0%
T120	0.663	0.583-0.732	<0.001	Strong	44.0%
Overall	0.687	0.612-0.748	<0.001	Strong	47.2%

[Table/Fig-6]: Correlation analysis between PAP and ETT cuff pressure changes.
All correlations significant at p<0.001 level
Correlation strength interpretation: r=0.1-0.3 (weak), r=0.3-0.5 (moderate), r=0.5-1.0 (strong) R^2 indicates the percentage of variance in ETT cuff pressure changes explained by PAP changes

Safety threshold exceedance: Safety-threshold analysis revealed concerning rates of pressure exceedance [Table/Fig-7]. The majority of patients required multiple interventions to maintain safe pressure parameters [Table/Fig-8].

Predictive factors for threshold exceedance were identified through multivariate analysis [Table/Fig-9].

Parameter	Threshold	Patients exceeding n (%)	Time to first exceedance (min)	Duration above threshold (min)
Peak Airway Pressure (PAP)	>40 cmH_2O	89 (84.8%)	32 (30-38)*	78 (65-95)*
ETT cuff pressure	>30 cmH_2O	105 (100%)	18 (15-25)*	102 (95-115)*

[Table/Fig-7]: Safety threshold analysis.
*Median (interquartile range)

Severity	PAP classification	n (%)	ETT cuff classification	n (%)
Normal	≤40 cmH_2O	16 (15.2%)	≤30 cmH_2O	0
Mild	40.1-45 cmH_2O	52 (49.5%)	30.1-40 cmH_2O	31 (29.5%)
Moderate	45.1-50 cmH_2O	31 (29.5%)	40.1-50 cmH_2O	58 (55.2%)
Severe	>50 cmH_2O	6 (5.8%)	>50 cmH_2O	16 (15.3%)

[Table/Fig-8]: Pressure elevation severity classification.

Safety analysis and required interventions: Intraoperative interventions were required in 98 patients (93.3%), with no major adverse events attributed to pressure elevations [Table/Fig-10]. Patients with severe pressure elevations (PAP >45 cmH_2O or ETT cuff >50 cmH_2O) required significantly more interventions than those with mild elevations (4.2±1.8 vs 2.1±1.2 interventions, p-value <0.001). Spinal surgery patients required more interventions than urological procedures (2.8±1.2 vs 1.9±0.8 per patient, p-value=0.002).

Subgroup analysis by procedure type: Patients were categorised as spinal surgery (n=67, 63.8%), urological procedures (n=28, 26.7%), and other procedures (n=10, 9.5%). Spinal surgery patients demonstrated the highest pressure elevations, with a mean maximum PAP of 35.2±2.8 cmH_2O versus 32.4±3.1 cmH_2O in urological procedures (p-value=0.003) and ETT cuff pressure of 44.8±4.2 cmH_2O versus 41.2±3.9 cmH_2O (p-value=0.001).

DISCUSSION

This prospective observational study demonstrated significant increases in both PAP and ETT cuff pressure when patients are turned from the supine to the prone position under general anaesthesia.

Variables	PAP >40 cmH_2O OR (95% CI)	p-value	ETT Cuff >50 cmH_2O OR (95% CI)	p-value
Age >50 years	1.67 (0.62-4.51)	0.312	2.41 (0.85-6.84)	0.098
Male gender	1.89 (0.71-5.03)	0.203	3.67 (1.23-10.94)	0.020*
BMI ≥25 kg/m²	3.24 (1.18-8.91)	0.023*	2.89 (1.01-8.28)	0.048*
Surgery duration >120 min	2.87 (1.05-7.84)	0.040*	1.92 (0.68-5.41)	0.218
Spinal surgery	2.15 (0.89-5.18)	0.089	1.34 (0.48-3.74)	0.577

[Table/Fig-9]: Pressure elevation severity classification.
*Statistically significant (p<0.05); OR: Odds ratio

Parameter	Frequency/result	Success rate	Clinical significance
Any intervention required	98 patients (93.3%)	91/98 (92.9%)	Universal monitoring need
ETT cuff pressure adjustment	93 patients (88.6%)	93/93 (100%)	Most common intervention
Mean interventions per patient	2.3±1.1	-	Median time: 18 min
Ventilator parameter modification	45 patients (42.9%)	40/45 (88.9%)	Median time: 35 min
Position micro-adjustment	12 patients (11.4%)	12/12 (100%)	Median time: 45 min
Bronchodilator therapy	8 patients (7.6%)	8/8 (100%)	Reactive airway response
Emergency repositioning	0 patients (0%)	-	No major complications
Spinal surgery subgroup	Higher intervention rate	89.6% success	2.8 interventions/patient
Urological surgery subgroup	Lower intervention rate	96.4% success	1.9 interventions/patient
Severe pressure elevation	37 patients (35.2%)	83.8% success	4.2 interventions/patient
Mild pressure elevation	52 patients (49.5%)	92.3% success	2.1 interventions/patient

[Table/Fig-10]: Comprehensive safety and intervention analysis.

These findings have important implications for anesthetic management during procedures requiring prone positioning.

Haemodynamic parameters: Present study demonstrated significant transient cardiovascular changes during prone positioning [Table/Fig-2]. Heart rate decreased significantly at T1 (80.05±9.49 bpm) and T15 (78.85±10.63 bpm) compared with baseline (82.44±10.43 bpm), while blood pressure parameters showed an initial elevation before stabilising after 30 minutes. These haemodynamic alterations were most pronounced during the first 15 minutes post-positioning, with complete stabilisation occurring thereafter. These findings align with previous studies by Poon KS et al., who reported significant mean blood pressure and heart rate changes at designated time points, and Manohar N and Manohar CS, who documented decreased heart rate and mean arterial pressure at 10, 15, and 20 minutes after prone positioning [7,20]. However, present study observation of transient blood pressure increases contrasts with other studies and may reflect our specific positioning protocols using Wilson frame support systems.

Peak Airway Pressure (PAP) changes: Present study revealed a substantial and progressive increase in PAP during prone positioning [Table/Fig-3]. PAP increased from baseline supine values of 19.03±3.35 cmH_2O to a maximum of 34.36±2.59 cmH_2O at T105, representing an 80.6% elevation that remained statistically significant throughout the procedure (p-value <0.001). Notably, the comparison between supine positions at the beginning and end of surgery showed no significant difference [Table/Fig-4], confirming that changes were position-dependent rather than time-related. This magnitude of increase substantially exceeds previous reports. Koh JC et al., documented only a 10.2% increase (13.7 to 15.1 cmH_2O), while Nam Y et al., reported moderate elevations during spinal surgery [8,9]. Present study findings likely reflect extended monitoring periods (up to 120 minutes vs 15-30 minutes in previous studies), different positioning techniques (Wilson frame vs Jackson table), and more sensitive measurement protocols compared with earlier investigations.

Endotracheal Tube (ETT) cuff pressure changes: ETT cuff pressure demonstrated marked and sustained increases during prone positioning [Table/Fig-5]. Baseline supine pressure of 24.64±2.99 cmH_2O increased to a maximum of 43.65±4.49 cmH_2O at T75, representing a 77% elevation with all measurements showing statistical significance (p-value <0.001). Unlike PAP, cuff pressure remained significantly elevated even after returning to the supine position at surgery completion [Table/Fig-6], suggesting cumulative effects of positioning and prolonged intubation. Our findings are consistent with studies by Mahoori A et al., who reported significant cuff pressure increases from 27.06±2 to 36.87±9 cmH_2O during position changes, and Kim D et al., who documented increases from 26.0 to 31.5±5.9 cmH_2O [21,22]. However, our universal threshold exceedance (100% of patients) exceeds the 65% rate reported by Kim D et al., [22], likely reflecting our more stringent safety threshold (30 cmH_2O vs. 35 cmH_2O) and extended monitoring duration.

Correlation between PAP and ETT cuff pressure: Present study demonstrated a strong positive correlation between PAP and ETT cuff pressure changes during prone positioning [Table/Fig-6]. The overall correlation coefficient of r=0.687 (95% CI: 0.612-0.748, p-value <0.001) remained consistently strong throughout all time points (r=0.654-0.723), explaining 47.2% of the variance in pressure changes. This sustained relationship suggests shared physiological mechanisms underlying both pressure alterations during prone positioning. This correlation analysis provides novel mechanistic insights not reported in previous literature, indicating that both parameters are influenced by similar factors, including increased intrathoracic pressure transmission and altered thoracic compliance during prone positioning.

Safety threshold analysis and interventions: Present study safety analysis revealed that 84.8% of patients exceeded PAP >40 cmH_2O and 100% exceeded ETT cuff pressure >30 cmH_2O [Table/Fig-7,8]. Interventions were required in 93.3% of patients, with ETT cuff pressure adjustment being the most common intervention (88.6% of patients) [Table/Fig-10]. Despite high intervention rates, no major adverse events occurred, demonstrating the effectiveness of proactive monitoring protocols. Predictive factors for threshold exceedance included BMI ≥25 kg/m², male gender and surgery duration >120 minutes [Table/Fig-9]. These findings provide practical guidance for identifying high-risk patients requiring enhanced monitoring strategies during prone positioning procedures.

Limitation(s)

The study has several limitations that should be considered when interpreting the findings. First, as a single-centre study, the results may lack generalisability to broader populations or different clinical settings. The inclusion of heterogeneous surgical procedures introduces potential confounding variables that could influence outcomes. Additionally, the absence of a control group limits the ability to make direct comparisons or assess the intervention's effectiveness relative to standard care. The study's reliance on short-term intraoperative monitoring, without long-term postoperative follow-up, restricts insights into sustained effects or complications. Furthermore, the sample was limited to ASA I-II patients, excluding higher-risk populations that may exhibit different responses. Potential observer bias in measurements could also affect the reliability of the data. Lastly, the restriction of participants to a specific age range (18-65 years) may limit applicability to younger or older individuals. These limitations highlight the need for further research to validate and expand upon the current findings.

CONCLUSION(S)

Present study demonstrated that prone positioning during general anaesthesia significantly increases both PAP and ETT cuff pressure. These increases are substantial, persistent throughout prone positioning, and potentially clinically significant. Haemodynamic parameters show transient changes during the initial 15 minutes after prone positioning but generally stabilise thereafter. These findings emphasise the importance of regular monitoring and appropriate adjustment of respiratory and haemodynamic parameters during procedures requiring prone positioning. Present study recommends routine monitoring of PAP with appropriate ventilator adjustments to maintain pressures within safe limits, regular measurement and adjustment of ETT cuff pressure to maintain it within the recommended range of 20-30 cmH_2O and close haemodynamic monitoring, particularly during the initial phase after prone positioning. Future research should focus on evaluating different prone positioning techniques to minimise these pressure changes, assessing the correlation between elevated pressures and postoperative complications and developing standardised protocols for managing these changes during prone positioning.

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