

A Study of Noninvasive Cardiac Output and Other Cardiorespiratory Parameters in Various Neurosurgical Positions

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ABSTRACT

Background: Neurosurgical patients are operated in supine, prone, lateral, and sitting positions, which cause physiological changes in cardiorespiratory parameters. Noninvasive cardiac output (NICO) monitor developed by Novamatrix Medical System Inc is a noninvasive cardiac output monitor, which also measures and displays other parameters like stroke volume, cardiac index, pulmonary capillary blood flow, alveolar and dead space ventilation, peak flow rates, airway pressures, and respiratory volumes. We felt that a study using the NICO monitor in anesthetized patients undergoing neurosurgery in different positions would quantify the cardiopulmonary changes, identify risk factors, and improve intraoperative management.

Materials and methods: A total of 40 consecutive patients undergoing neurosurgical procedures—20 in prone, 16 in lateral and 4 in sitting position—were studied. The hemodynamic and cardiorespiratory parameters were noted in supine position about 15 minutes after induction of general anesthesia using standard protocol and 15 minutes after giving surgical position using NICO monitor.

Conclusion: We conclude that under anesthesia, the prone and sitting positions negatively affect derived cardiac parameters like cardiac output, cardiac index, and stroke volume, and lateral position tends to improve these parameters while the respiratory parameters are not significantly affected.

Keywords: Lateral position, Neurosurgery, NICO monitor, Noninvasive cardiac output, Positioning under anesthesia, Prone position, Sitting position.

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INTRODUCTION

Changes in cardiorespiratory parameters often occur with change of position. These changes have been studied in experimental animals,¹ healthy volunteers,^{2,3} and

anesthetized patients⁴ using mainly invasive methods to measure cardiac output. With the availability of a non-invasive monitor which measures cardiac and respiratory parameters, we felt that a study assessing the cardiorespiratory changes in different surgical positions would be helpful in defining risk factors and improving intraoperative management.

Neurosurgical procedures including intracranial and spine surgeries require different patient positions like supine, prone, lateral, and sitting for optimum surgical access. We decided to use the NonInvasive Cardiac Output (NICO) monitor developed by Novamatrix Medical System Inc (600 Unicorn Park Dr # 4, Woburn, MA 01801, United States) to measure parameters like cardiac output, stroke volume, cardiac index, pulmonary capillary blood flow, minute ventilation (MV), alveolar minute ventilation (MValv), tidal volume (TV), dead space, peak inspiratory pressure (PIP), and peak expiratory flow (PEF) and document differences with change in position. Any major adverse effect related with positioning were also noted.

MATERIALS AND METHODS

After Institutional Review Committee approval, the study was carried out in 40 consenting, adult neurosurgical patients, of either sex, between 18 and 60 years of age, of American Society of Anesthesiologists Physical Status Classification I, II, or III, undergoing elective surgeries in prone, lateral, or sitting position. Exclusion criteria were preexisting restrictive, obstructive, or infective respiratory diseases, associated cardiovascular diseases, hemodynamically unstable patients, weight >90 kg, height <145 cm, Glasgow Coma Score (GCS) <11, and emergency intracranial procedures.

METHODOLOGY

A complete clinical history and examination including patient height and weight and all relevant investigations were carried out and written consent was obtained.

Patients were taken on table; pulse oximeter, cardioscope, and blood pressure (BP) cuff were attached and all vital parameters were noted. Peripheral and central venous access was obtained and central venous pressure (CVP) was measured. Patients having CVP less than 3 cm

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of water were excluded. All patients received 10 ml/kg normal saline in the first 30 minutes.

All patients received intravenous (IV) injection of glycopyrrolate 0.004 mg/kg, Ranitidine 1 mg/kg, Pentazocine 0.5 mg/kg, and Midazolam 0.05 mg/kg as premedication. Injection thiopental sodium 4–6 mg/kg IV and injection vecuronium 0.1 mg/kg IV were used for induction of general anesthesia and tracheal intubation. Anesthesia was maintained with O₂ + N₂O (50:50) + propofol + vecuronium bromide infusions. Controlled

ventilation using circle absorber system with Datex Ohmeda Excel 210 SE anesthesia machine and ventilator was used. An arterial blood gas sample was collected and sent for analysis.

Approximately 15 minutes after induction, all the baseline vital parameters were noted. With the patient in supine position, the NICO monitor was attached to the breathing system with adjusted rebreathing loop as shown in Figure 1. The patient data in the form of weight in kilogram, height in centimeter, and arterial

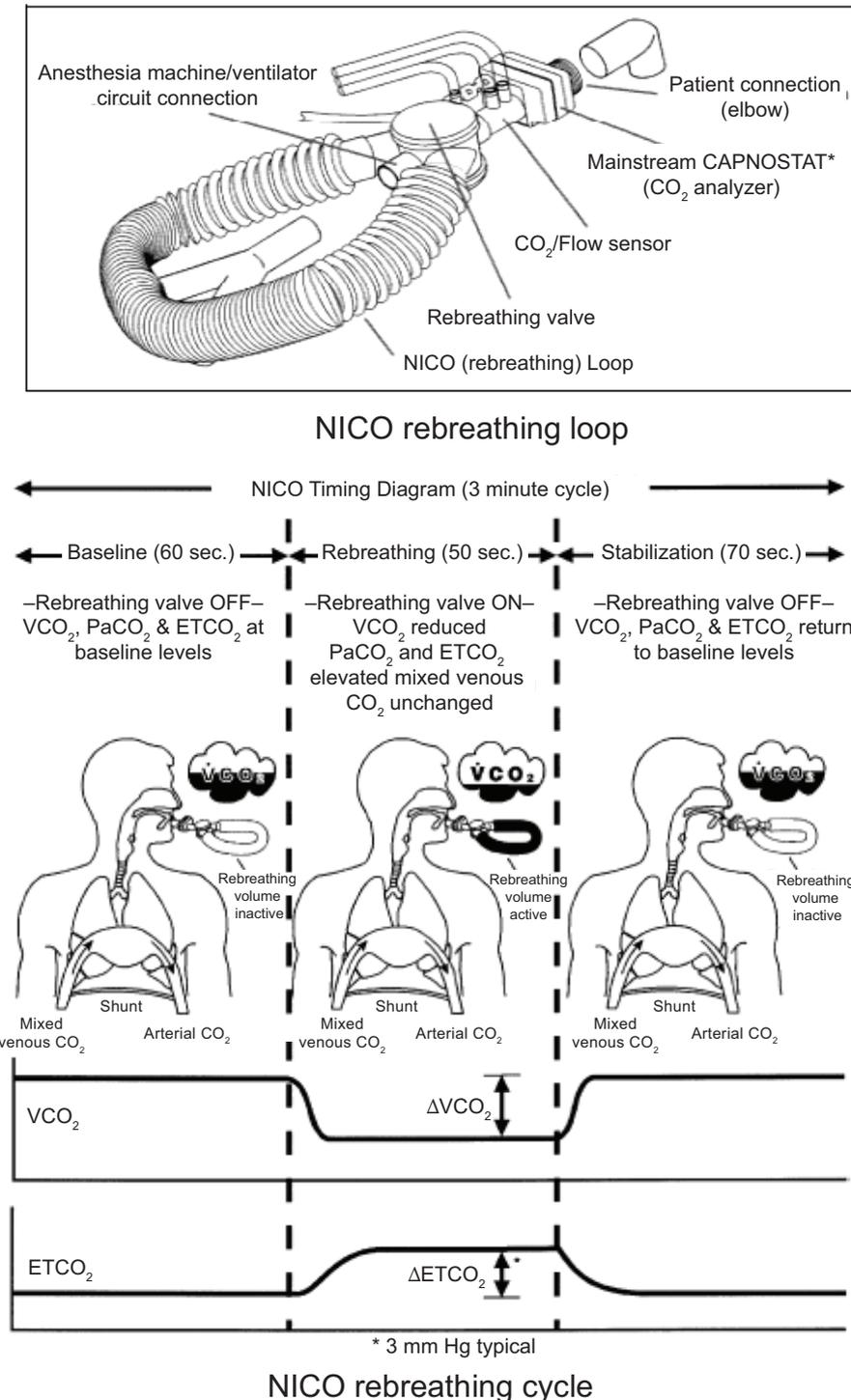


Fig. 1: Noninvasive cardiac output working principle

blood gases were fed into the NICO monitor and NICO pulse oximeter probe was attached. The following cardiorespiratory parameters were noted: HR (heart rate), BP, CVP, SpO₂ (oxygen saturation), RR (respiratory rate), MValv, MV, PIP, TV, PEF, the baseline CO₂ elimination (VCO₂), and ETICO₂ (end tidal carbon dioxide).

The rebreathing cycle was then started. This consisted of diversion of the patient's inhaled and exhaled gases every 3 minutes through the NICO loop for 50 seconds by the rebreathing valve, preventing normal volumes of CO₂ from being eliminated. As a result, VCO₂ decreased and the concentration of CO₂ in the pulmonary artery (CaCO₂) increased, which was reflected in the ETICO₂. The monitor, utilizing the differential Fick principle for CO₂, calculated and displayed the derived parameters like stroke volume, cardiac output, cardiac index, and pulmonary capillary blood flow. Three such consecutive readings were taken and the average of these readings was noted.

The required neurosurgical position—prone, lateral, or sitting—was thereafter given, taking care not to hamper respiration, keeping the abdomen free, and padding all pressure points. Vertical bolsters were used to give prone position. While giving the sitting position, an additional 10 ml/kg of lactated Ringer's solution was infused and crepe bandages were applied on lower limbs.

A total of 15 minutes after positioning, all the cardiorespiratory parameters mentioned above were noted. Keeping the ventilator settings constant, the rebreathing cycle was initiated, and the average of the three readings for each of the derived parameters was noted. Any major cardiorespiratory complication related to change in position was also noted.

The data thus obtained were subjected to statistical analysis using paired and unpaired student's *t*-test and chi-square test for each position. A *p* value <0.05 was considered as significant and *p* value <0.005 was considered as highly significant.

Table 1: Demography of the patients and surgeries

Parameters	Prone position	Lateral position	Sitting position
No. of patients (n)	20	16	04
Mean age (years)	35.45 ± 13.85	38.06 ± 10.56	30.75 ± 5.12
Sex (M/F)	12/8	8/8	2/2
Mean height (cm)	161.30 ± 6.55	161.63 ± 8.40	161.50 ± 5.50
Mean weight (kg)	57.35 ± 8.81	58.69 ± 8.45	56.00 ± 6.27
Intracranial surgeries	04	15	04
Spine surgeries	16	01	00

RESULTS AND ANALYSIS

Table 1 shows demographic and surgery-wise distribution of patients. Only four patients were given sitting position as it had fallen out of favor at that time.

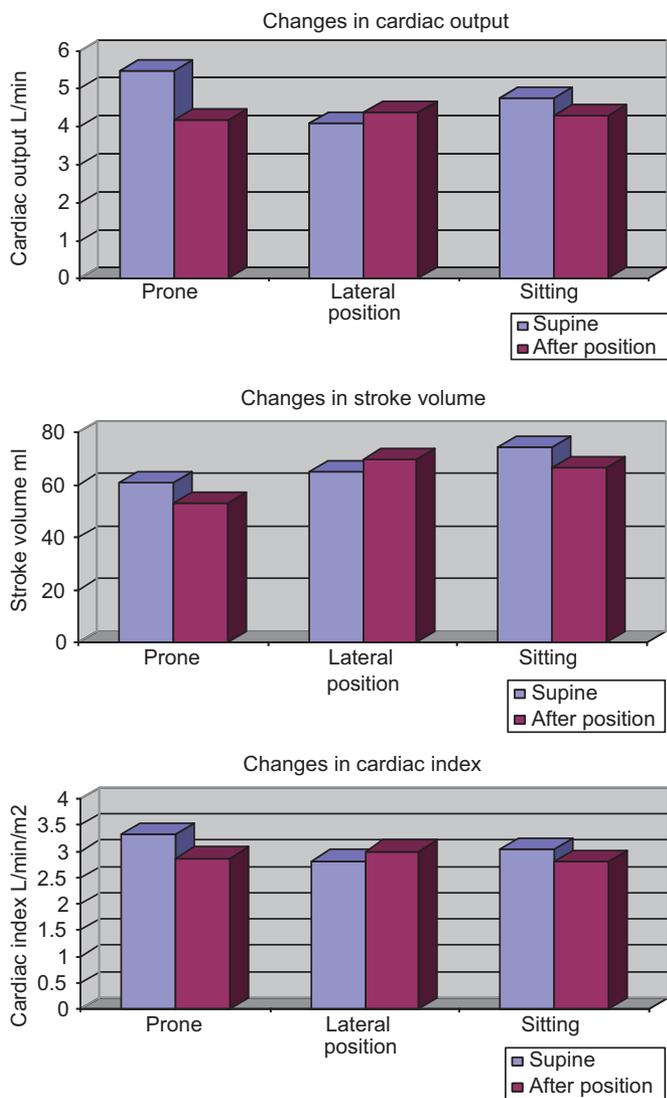
Table 2 and Graph 2 show the changes in cardiovascular parameters with change of position. The mean HR reduced in prone and lateral position and increased in the sitting position. Though statistically significant, these changes were clinically significant only in sitting position and happened in spite of additional IV fluids given before and during positioning in these patients. Mean systolic BP showed a statistically significant (*p* < 0.05) but clinically insignificant decrease in patients given prone position and increase in lateral position. All patients in the sitting position showed a marked decrease in mean systolic pressure. However, the small sample size precludes any statistical significance.

The prone position was associated with a statistically very highly significant decrease in the mean cardiac output from 5.48 ± 1.10 to 4.19 ± 0.85 l/min (*p* = 0.000) (Table 2 and Graph 1), statistically highly significant decrease in mean stroke volume from 60.90 ± 16.91 to 53.05 ± 15.08 ml, and a decrease in cardiac index and pulmonary capillary blood flow.

Table 2: Cardiovascular parameters with change of position

Parameters	Prone			Lateral			Sitting		
	Before	After	<i>p</i> -value	Before	After	<i>p</i> -value	Before	After	<i>p</i> -value
Heart rate (bpm)	89.65 ± 14.00	84.40 ± 12.62	0.022	87.38 ± 10.75	82.69 ± 12.22*	0.021	78.00 ± 11.77	86.00 ± 9.09*	0.022
Systolic blood pressure (mm Hg)	117.80 ± 6.38	114.70 ± 5.32	0.024	115.38 ± 6.22	120.00 ± 7.04	0.037	121.50 ± 8.69	103.50 ± 4.72	0.007
Cardiac output (l/min)	5.48 ± 1.10	4.19 ± 0.85	0.000	4.08 ± 0.63	4.38 ± 0.76	0.067	4.75 ± 0.71	4.30 ± 0.57	0.037
Stroke volume (ml)	60.90 ± 16.91	53.05 ± 15.08	0.001	64.81 ± 13.12	69.50 ± 14.54	0.011	74.50 ± 10.63	66.50 ± 8.22	0.022
Cardiac index (l/min/m ²)	3.32 ± 0.85	2.87 ± 0.87	0.000	2.82 ± 0.38	3.00 ± 0.63	0.111	3.05 ± 0.30	2.80 ± 0.28	0.015
PCBF (l/min)	4.82 ± 0.90	4.22 ± 0.99	0.000	2.94 ± 0.46	3.01 ± 0.70	0.509	3.47 ± 0.15	3.20 ± 0.00	0.035

PCBF: Pulmonary capillary blood flow



Graph 1: Graphs of cardiac output, stroke volume, and cardiac index

The lateral position showed statistically insignificant increase in cardiac output from 4.08 ± 0.63 to 4.38 ± 0.76 l/min, statistically significant increased stroke volume from 64.81 ± 13.12 to 69.50 ± 14.54 ml, and a small increase in cardiac index and pulmonary capillary blood flow.

The sitting position showed statistically significant decreased cardiac output from 4.75 ± 0.71 to 4.30 ± 0.57 l/min, decreased stroke volume from 74.50 ± 10.63 to 66.50 ± 8.22 ml, decreased mean cardiac index from 3.05 ± 0.30 to 2.80 ± 0.28 l/min/m², and decreased pulmonary capillary blood flow.

Table 3 summarizes the respiratory changes with positioning. There was no change in expired TV, dead space, alveolar TV, PIP, PEF, or change in ET_{CO}₂ following any position. Significant reduction in MV from 5.54 ± 0.68 to 5.40 ± 0.68 l/min with corresponding reduction in MV_{alv} ($p < 0.05$) was noted in the prone position. No significant change in MV was noted in lateral position. All patients who were given sitting position showed a significant increase in both MV and MV_{alv}. Carbon dioxide elimination reduced significantly from 121.05 ± 30.77 to 112.30 ± 26.49 ml/min ($p = 0.025$) after prone positioning, but no significant change from baseline was noted in lateral or sitting position.

There were no position-related adverse effects noted during the study.

DISCUSSION

A change in patient position causes cardiorespiratory effects due to change in venous return, peripheral pooling of blood, altered resistance to diaphragmatic move-

Table 3: Respiratory parameters with change of position

Parameters	Prone			Lateral			Sitting		
	Before	After	p-value	Before	After	p-value	Before	After	p-value
MV (l/min)	5.54 ± 0.68	5.40 ± 0.68	0.025	4.94 ± 0.38	4.95 ± 0.39	0.915	5.55 ± 0.50	3.65 ± 0.20	0.014
MValv (l/min)	3.95 ± 0.64	3.80 ± 0.67	0.036	3.36 ± 0.31	3.18 ± 0.30	0.002	5.85 ± 0.41	4.02 ± 0.28	0.022
Vte (ml)	430.98 ± 51.21	444.00 ± 46.65	0.612	410.31 ± 48.44	413.56 ± 46.36	0.130	419.00 ± 35	422.50 ± 36	0.310
Vtalv (ml)	274.05 ± 61.52	275.85 ± 64.32	0.706	248.94 ± 21.86	247.25 ± 24.34	0.557	272.00 ± 20.33	277.00 ± 21.81	0.195
Vdaw (ml)	171.25 ± 32.77	171.10 ± 32.40	0.942	146.44 ± 19.40	147.31 ± 19.15	0.807	134.50 ± 4.4	138.00 ± 5.16	0.432
PIP (cm H ₂ O)	14.10 ± 2.15	15.45 ± 2.83	0.070	15.00 ± 2.21	14.94 ± 2.14	0.849	15.50 ± 0.57	15.75 ± 1.25	0.638
PEF (l/min)	37.30 ± 5.93	38.15 ± 6.05	0.073	34.63 ± 2.24	35.06 ± 2.29	0.263	33.75 ± 1.25	34.00 ± 1.63	0.718
VCO ₂ (ml/min)	121.05 ± 30.27	112.30 ± 26.49	0.032	155.31 ± 15.05	151.38 ± 13.75	0.373	146.00 ± 5.58	143.50 ± 14.27	0.744
ETCO ₂ (mm Hg)	32.60 ± 2.08	32.60 ± 2.54	1.000	33.44 ± 1.63	32.56 ± 1.03	0.115	32.50 ± 1.0	33.25 ± 0.95	0.486

MV: Minute ventilation; MValv: Alveolar minute ventilation; PIP: Peak inspiratory pressure; PEF: Peak expiratory flow; VCO₂: CO₂ elimination; ET_{CO}₂: End tidal carbon dioxide



ment, and ventilation perfusion mismatch along with the blunting of autonomic nervous system under general anesthesia. Heart rate and BP can be monitored clinically or by regularly used monitors. But parameters like stroke volume, cardiac output, cardiac index, alveolar ventilation, and airway pressure need special or invasive monitors like arterial cannulation, pulmonary artery catheterization, airway pressure monitors, etc. A noninvasive monitor measuring most of these parameters would definitely add to the armamentarium of the anesthesiologist.

Non invasive cardiac output is a multichannel, multi-functional monitor useful in patients with endotracheal tube *in situ* under general anesthesia. The noninvasive measurement of cardiac output is done using the partial rebreathing technique and application of collected data to the differential Fick equation. The monitor uses a rebreathing loop with valve to create partial rebreathing and collects data on the changes in the rate of VCO_2 and $ETCO_2$. It subsequently applies this data to the differential Fick equation to calculate cardiac output.

The differential Fick equation for partial rebreathing cardiac output can be reduced by derivation as follows:⁵

$$CO = \frac{VCO_{2N} - VCO_{2R}}{CaCO_{2N} - CaCO_{2R}} = \frac{\Delta VCO_2}{\Delta CaCO_2} = \frac{\Delta VCO_2}{\Delta ETCO_2}$$

where CO represents the cardiac output, VCO_{2N} and VCO_{2R} are the volumetric CO_2 elimination, $CaCO_{2N}$ and $CaCO_{2R}$ are the arterial CO_2 concentrations during normal and rebreathing periods, respectively, and ΔVCO_2 and $\Delta CaCO_2$ represent the changes in VCO_2 and $CaCO_2$ between normal and rebreathing periods. Since the change in $CaCO_2$ is reflected in and measured by the change in $ETCO_2$, cardiac output is equal to the ratio of change in rate of volumetric CO_2 elimination and change in $ETCO_2$ levels.

Haryadi et al^{6,7} and Bailey et al⁸ evaluated this technique and found it to be an easy-to-use, automated, clinically acceptable continual measurement of cardiac output. The small increase in $ETCO_2$ was not found to be harmful and could be easily tolerated by the patient. Loeb et al⁹ while comparing NICO monitor with invasive bolus and continuous thermodilution technique and Kothari et al¹⁰ while comparing it with bolus thermodilution technique, thermal-based continuous cardiac output, pulse contour cardiac output technique concluded that NICO is least expensive and easy to use. Similarly, Botero et al¹¹ found it to be a good alternative to pulmonary artery catheterization (PAC) and direct arterial flow techniques for cardiac output measurement.

Cardiovascular Parameters

A fall in cardiac output in prone position is expected due to reduced venous return caused by increased

intra-abdominal pressure with compression of inferior vena cava and abdominal aorta and decreased thoracic and ventricular compliance. However, the magnitude of reduction in the present study was more than expected, given the fact that HR and systolic BP remained relatively stable. Blood pressure was probably maintained due to peripheral vasoconstriction with increased systemic vascular resistance as well as pulmonary vascular resistance as documented in a study by Backofen and Schauble.⁴

Wadsworth et al² had found similar results in a study of 20 healthy volunteers to assess the effect of four different surgical positions. Backofen and Schauble⁴ also noted reduced cardiac output with no change in HR and systolic BP in anesthetized patients during prone positioning. Sudheer et al¹² also had similar results.

Srivastava et al¹³ recommended that the abdomen should be kept free and legs should be elevated in prone position to minimize reduced cardiac output. Alexianu et al¹⁴ reported a case of hemodynamic collapse in a child positioned prone on transverse bolsters, for spine surgery, treated by repositioning on longitudinal bolsters.

The positive cardiovascular effects in the lateral position may be due to reduction in pressure on inferior vena cava and maintained negative intrathoracic pressure leading to improved venous return and positive inotropic effect. Nakao et al¹ in a study in experimental animals concluded that lateral position significantly increases intracardiac pressures and cardiac output. However, Kamenik³ found drastic decrease in cardiac index and stroke volume and significant increase in HR in healthy volunteers placed in lateral position with 30° head up tilt. The head up tilt may explain the discrepancy.

The reduction of all cardiovascular parameters in the sitting position may be attributed to the peripheral pooling of blood and decreased venous return. Buhre et al¹⁵ who measured simultaneous changes in intrathoracic blood volume using thermo dye dilution technique, in anesthetized patients with change of body position, found a significant decrease in intrathoracic blood volume, cardiac index, stroke volume index and arterial pressure.

Respiratory Parameters

In our study, we found that respiratory parameters were not clinically affected by change in patient positioning. Palmon et al¹⁶ in their study of effect of type of frame and body habitus on pulmonary mechanics demonstrated that prone positioning during anesthesia results in a frame-dependent decrease in pulmonary compliance with no effect of body mass index. Soro et al¹⁷ demonstrated no significant changes in the alveolar dead space to TV ratio but improved oxygenation in prone position. Similarly, Pelosi et al¹⁸ found statistically significant

modifications in respiratory and chest wall resistance, marked improvement in lung volume and oxygenation, and similar delivered TVs in prone position.

Thus, our study demonstrated that prone position and sitting positions showed negative hemodynamic and cardiovascular effects, while the lateral position showed improvement in the cardiovascular parameters as compared with supine position. The respiratory parameters get minimally affected in these positions if the patient is given proper surgical positioning.

CONCLUSION

We conclude that the prone and sitting positions negatively affect derived cardiac parameters like cardiac output, cardiac index, and stroke volume, while the lateral position tends to improve these parameters. Special care with extra vigilance toward hemodynamic monitoring and fluid management is required during prone and sitting positions. The respiratory parameters do not change significantly. A study involving larger number of patients would be appropriate for finding the effect of sitting position on cardiorespiratory parameters. We also found the NICO monitor to be useful and easy to use. Its use can be recommended in patients undergoing general anesthesia with endotracheal intubation in whom cardiac output needs to be monitored and PAC is difficult, not indicated, or not available.

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