Research Article

A study of non invasive cardiac output and other cardiorespiratory parameters in various neurosurgical positions

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Abstract

Neurosurgical patients are operated in supine, prone, lateral and sitting positions, which cause physiological changes in cardiorespiratory parameters. Various monitors, both non invasive and invasive are used to monitor these changes. NICO monitor developed by Novametrix Medical System Inc is a non-invasive cardiac output monitor, which also measures and displays various 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 anaesthetised patients being operated in different positions would provide a complete characterization of cardiopulmonary function, help in defining risk factors and improve intraoperative management. Hence, forty consecutive patients undergoing neurosurgical procedures- twenty in prone, sixteen in lateral and four in sitting position were studied. The haemodynamic and cardiorespiratory parameters were noted in supine position about 15 minutes after induction of general anaesthesia using standard protocol and 15 minutes after giving surgical position using NICO monitor. We concluded that under anaesthesia, while the respiratory parameters are not significantly affected, the prone and sitting position negatively affect derived cardiac parameters like cardiac output, cardiac index and stroke volume and lateral position tends to improve these parameters.
Keywords: Non invasive cardiac output, NICO monitor, Neurosurgery, Positioning under Anaesthesia, Prone position, Lateral position, Sitting position.

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INTRODUCTION

Changes in cardio-respiratory parameters often occur with change of position. These changes have been studied in experimental animals[1], healthy volunteers[2,3] and anaesthetised patients[4]. However most of these studies involve use of invasive methods to measure parameters like cardiac output. In many surgical situations such invasive access and monitors are neither available nor indicated. With the availability of a non invasive monitor capable of measuring a variety of cardiac and respiratory parameters, we felt that a study assessing the various cardio-respiratory changes in different surgical positions would be helpful. Such a study would help in defining risk factors and improve intraoperative management in various neurosurgical positions. Neurosurgical procedures including intracranial and spine surgeries require different patient positions for optimum surgical access. These include supine, prone, lateral and sitting positions. We decided to use the NICO (Non Invasive Cardiac Output) monitor developed by Novametrix Medical System Inc to measure parameters like cardiac output, stroke volume, cardiac index, pulmonary capillary blood flow, minute ventilation, alveolar minute ventilation, tidal volume, dead space, peak inspiratory pressure and peak expiratory flow and document differences with change in position. Changes in haemodynamic parameters and any major adverse effect related with positioning were also noted.

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MATERIALS AND METHODS

After Institutional Review Committee approval, the study was carried out in 40 adult neurosurgical patients undergoing elective surgeries in prone, lateral or sitting position. We included consenting patients of either sex between 18 to 60 years of age of ASA Physical Status Classification I, II or III. Exclusion criteria comprised of pre-existing restrictive, obstructive or infective respiratory diseases, associated cardiovascular diseases, haemodynamically unstable patients, Weight > 90 kg, Height < 145 cm, Glasgow Coma Score (GCS) < 11 and Emergency intracranial procedures.

METHODOLOGY

A complete clinical history, thorough clinical examination including patient height and weight and all relevant investigations appropriate for the procedure were carried out to ascertain inclusion into study and written consent was obtained. Once inside the operation theatre, pulse oximeter, cardioscope and blood pressure cuff were attached to the patient and all vital parameters were noted. Peripheral and central venous access was obtained and central venous pressure was measured. Patients having CVP less than 3 cms of water were excluded. All patients received 10 ml/kg normal saline in first half an hour. All patients received intravenous injection of Glycopyrrolate 0.004mg/kg, Ranitidine 1mg/kg, Pentazocine 0.5 mg/kg, and Midazolam 0.05 mg/kg as premedication. Injection Thiopentone sodium 4-6 mg/kg I.V. and Injection Vecuronium 0.1 mg/kg I.V. was used for induction of general anaesthesia and tracheal intubation. Anaesthesia was maintained with 0_2 + N_20 (50:50) + Propofol + Vecuronium Bromide infusions. Controlled ventilation using circle absorber system with Datex Ohmeda Excel 210 SE anaesthesia machine and ventilator was used in all patients. 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 kg, height in cms and arterial 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(Blood Pressure), CVP (Central Venous Pressure), SpO_2 (Oxygen Saturation), RR (Respiratory Rate), MValv (Alveolar Minute Ventilation), MV (Minute Ventilation), PIP (Peak Inspiratory pressure), TV (Tidal Volume), PEF (Peak Expiratory Flow), the baseline CO_2 elimination (VCO_2) and $ETCO_2$ (End tidal Carbon Dioxide). The rebreathing cycle was then started. This consisted of diversion of the patient's inhaled and exhaled gases every three minutes through the NICO loop for 50 seconds by the rebreathing valve, preventing normal volumes of CO_2 from being eliminated. As a result, the CO_2 elimination decreased and the concentration of CO_2 in the pulmonary artery ($CaCO_2$) increased which was reflected in the $ETCO_2$. The monitor, utilising the differential Fick Principle for CO_2, 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. Fifteen 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 was 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.

RESULTS AND ANALYSIS

Table 1 shows demographic and surgery wise distribution of patients. Sitting position was given in only four patients as this position had fallen out of favour of neurosurgeons and neuroanaesthetists at that time. Table 2 and Figure 2 show the changes in cardiovascular parameters with change of position. The mean heart rate 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 intravenous fluids given before and during positioning in these patients. Mean systolic blood pressure 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 liters/min to 4.19 ± 0.85 liters/min (Table 2 and Figure 2). Mean stroke volume in prone position decreased from 60.90 ± 16.91 ml to 53.05 ±

15.08 ml which was statistically highly significant. There was corresponding decrease in cardiac index and pulmonary capillary blood flow in prone position. The lateral position showed increase in cardiac output from 4.08 ± 0.63 liters/min to 4.38 ± 0.76 liters/min. This increase in cardiac output was however statistically insignificant. Stroke volume increased from 64.81 ± 13.12 ml to 69.50 ± 14.54 ml which was found to be statistically significant. The cardiac index and pulmonary capillary blood flow showed a small increase in lateral position. The sitting position showed statistically significant decrease in cardiovascular parameters. The cardiac output decreased from 4.75 ± 0.71 liters/min to 4.30 ± 0.57 liters/min and stroke volume decreased from 74.50 ± 10.63 ml to 66.50 ± 8.22 ml. The mean cardiac index decreased from 3.05 ± 0.30 liters/min/m^2 to 2.80 ± 0.28 liters/min/m^2 and the pulmonary capillary blood flow also decreased in sitting position. Table 3 denotes changes in respiratory parameters with positioning. There was no change in expired tidal volume following any position as ventilatory parameters were kept unchanged. There was no significant change in dead space or alveolar tidal volume following prone, lateral or sitting position as depicted in the above table. However, in the prone position, there was significant reduction in minute ventilation from 5.54 ± 0.68 to 5.40 ± 0.68 liters/min. There was also a corresponding reduction in alveolar minute ventilation ($p < 0.05$). No significant change in MV was noted in lateral position. All patients who were given sitting position showed a significant increase in both minute ventilation and alveolar minute ventilation. The peak inspiratory pressure and peak expiratory flow showed no significant change following any patient position suggesting that none of the positions offered more resistance to ventilation. There was no significant change in carbon dioxide elimination from baseline value noted in either lateral or sitting position. However, after prone positioning carbon dioxide elimination reduced significantly from 121.05 ± 30.77 to 112.30 ± 26.49 ml/min after positioning. As shown in Table 3, there was no significant change in $ETCO_2$ after surgical positioning in any group, with same amount of ventilation. Thus in the present study, it was found that after giving prone position there was no significant change in respiratory parameters where as there was significant reduction in cardiac output and related parameters. Lateral position was found to have no effect on respiratory parameters and had beneficial effect on cardiac parameters. The small change in respiratory parameters and considerable fall in haemodynamic as well as cardiac parameters in the sitting position could not be statistically analysed due to the small sample size. There were no position related adverse effects noted during the study.

Table 1: Demography of the patients and surgeries

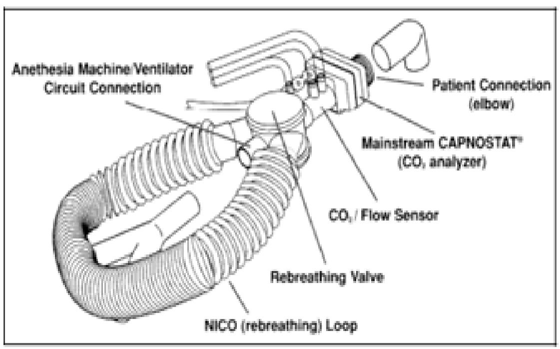
Parameters	Prone position	Lateral position	Sitting position
No. of patients (n)	20	16	04
Mean age (yrs)	35.45 ± 13.85	38.06 ± 10.56	30.75 ± 5.12
Sex (M / F)	12 / 8	8 / 8	2 / 2
Mean height (cm)	161.30 ± 6.55	161.63 ± 8.40	161.50 ± 5.50
Mean weight (kg)	57.35 ± 8.81	58.69 ± 8.45	56.00 ± 6.27
Intracranial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

Table 2: Cardiovascular Parameters with Change of Position

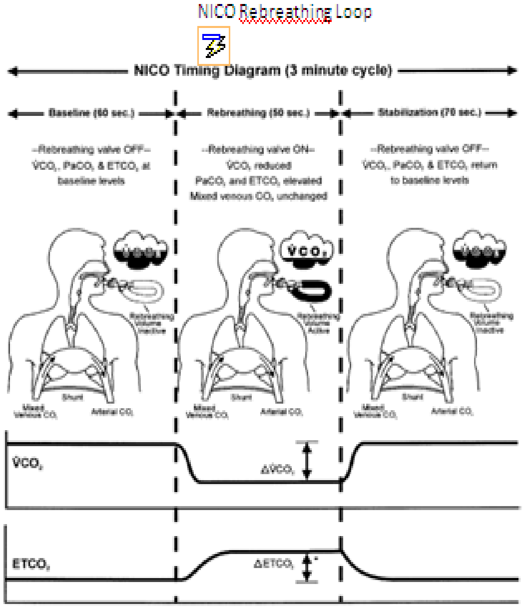
	(PRONE)			(LATERAL)			(SITTING)		
Parameters	Before	After	p value	Before	After	p value	Before	After	p value
Heart rate(bpm)	89.65 ± 14.00	84.40 ± 12.62	0.022	87.38 ± 10.75	82.69 ± 12.22*	0.021	78.00 ± 11.77	86.00 ± 9.09*	0.022
Systolic blood pressure (mm Hg)	117.80 ± 6.38	114.70 ± 5.32	0.024	115.38 ± 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

Table 3: Respiratory Parameters with Change of Position

	(PRONE)			LATERAL)			(SITTING)		
Parameters	**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_2O)	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
$ETCO_2$(mmHg)	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

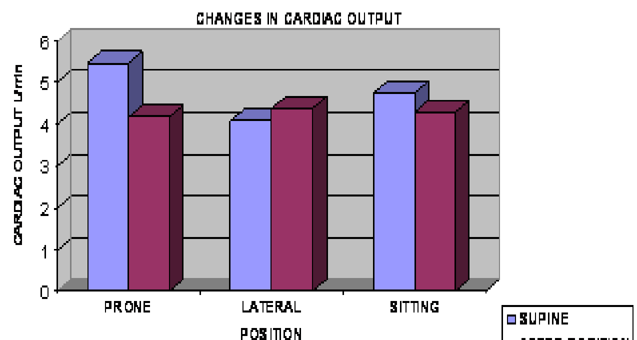


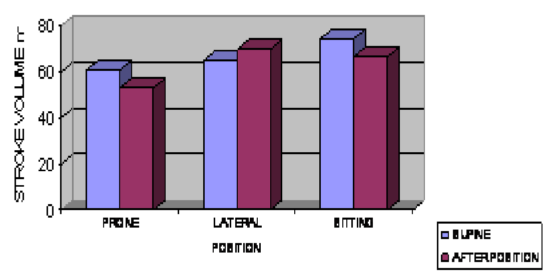
NICO Rebreathing Loop



NICO Rebreathing cycle

Figure 1: NICO Working Principle





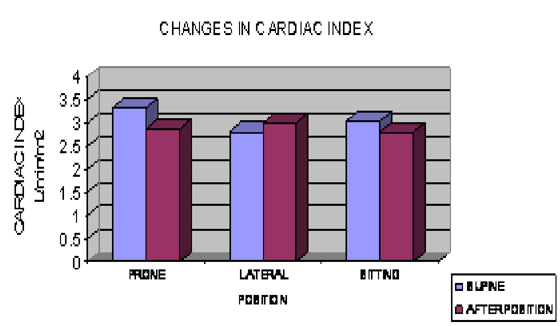


Figure 2: Graphs of Cardiac output, Stroke volume and Cardiac Index

DISCUSSION

A change in patient position causes changes in various cardiorespiratory parameters due to change in venous return, peripheral pooling of blood, altered resistance to diaphragmatic movement and ventilation perfusion mismatch. These effects along with the blunting of autonomic nervous system under general anaesthesia are known to alter the cardiorespiratory parameters. An educated anaesthesiologist can ensure patient safety by an awareness of these physiological changes. Some of these changes like heart rate and blood pressure can be monitored clinically or by regularly used monitors. But other cardiorespiratory parameters like stroke volume, cardiac output, cardiac index, alveolar ventilation and airway pressure need special or invasive monitors which may include central venous cannulation, arterial cannulation, pulmonary artery catheterisation and airway pressure monitors. A non invasive monitor capable of measuring a majority of these parameters would definitely add to the armamentarium of the anaesthesiologist. NICO is a multi-channel, multifunctional monitor which can be used in patients with endotracheal tube in situ under general anaesthesia. The non invasive measurement of cardiac output is accomplished by 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 CO_2 elimination (VCO_2) and the end-tidal CO_2 ($ETCO_2$). 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]:

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

Where C.O. 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 D G *et al*[6,7,] Bailey P L *et al*[8] studied partial carbon dioxide rebreathing Fick technique for non invasive measurement of cardiac output and found it to be an easy to use, automated, clinically acceptable continual measurement of cardiac output. The small increase in end tidal carbon dioxide was not found to be harmful and could be easily tolerated by the patient. Loeb R G *et al*[9] while comparing non invasive cardiac output monitor with invasive bolus and continuous thermodilution technique and Kothari N *et al*[10] while comparing it with bolus thermodilution technique (TDCO), thermal based continuous cardiac output (CCO), pulse contour cardiac output (Pulse CO) technique, concluded that NICO is least expensive and easy to use. Similarly, Botero M[11] *et al* found it to be a good alternative to PAC (Pulmonary Artery Catheterization) and direct arterial flow techniques for cardiac output measurement.

CARDIOVASCULAR PARAMETERS

A fall in cardiac output due to decreased thoracic compliance was expected in the prone position. However the magnitude of reduction in the present study was more than expected, given the fact that heart rate and systolic blood pressure 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 R *et al*[2] had found similar results with no change in heart rate and systolic blood pressure and significantly decreased cardiac index in a study of 20 healthy volunteers to assess the effect of four different surgical positions. Backofen and Schauble[4] also did not find any change in heart rate, systolic blood pressure but noted reduced cardiac output, in anaesthetized patients when turned from supine to prone position mainly for spine surgeries. Sudheer P S *et al*[12] in their study concluded that turning anaesthetised healthy patients prone produces a clinically significant reduction in cardiac output and cardiac index. A reduction in venous return due to increased intra abdominal pressure with subsequent compression of IVC and abdominal aorta in prone position and decreased ventricular compliance due to raised intra-thoracic pressure contribute to the fall in cardiac output. Shrivastava S. *et al*[13] wrote from their experience that the decrease in cardiac output is due to decreased venous return and therefore abdomen should be kept free and legs should be elevated in prone position to minimize this effect. Alexianu D *et al*[14] reported a case of haemodynamic collapse in a child following prone position, on transverse bolsters, for spine surgery, which could be corrected only after positioning the patient on longitudinal bolsters. Thus cardiorespiratory parameters can significantly worsen if abdomen is not kept free between the bolsters. The positive effect on cardiovascular parameters in the lateral position may be due to reduction in pressure on inferior vena cava and maintenance of the negativity of intrathoracic pressure leading to improvement in the venous return and positive inotropic effect. This is supported by a study from Nakao S *et al*[1] in experimental animals. They concluded that a change from supine to lateral position significantly increases intracardiac pressures and cardiac output. However, Kamenik M[4] found drastic decrease in cardiac index and stroke volume and associated significant increase in heart rate in healthy volunteers when they were placed in right or left 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. This is seconded by Buhre W *et al*[15] who measured simultaneous changes in intrathoracic blood volume caused by change in body position in anaesthetised patients using thermo dye dilution technique. They found that the change in body position caused a significant decrease in intrathoracic blood volume, cardiac index, stroke volume index and arterial pressure.

RESPIRATORY PARAMETERS

In our study, we found that minute ventilation and alveolar minute ventilation, tidal volume and airway dead space was not much clinically affected due to change in patient positioning. The ventilator settings were kept constant in both the positions in each patient. The peak inspiratory pressure and peak expiratory flow showed no significant changes in our study following any patient positioning. All the patients were properly positioned in the surgical position leading to minimum effect on the airway resistance. Palmon S C *et al*[16] in their study of effect of type of frame and body habitus on pulmonary mechanics demonstrated that prone positioning during anesthesia results in a decrease in pulmonary compliance that is frame-dependent but not affected by body mass index. Soro M *et al*[17] in a study demonstrated that there was no significant changes in the alveolar dead space to tidal volume ratio. They however mentioned that oxygenation tended to improve in prone position. Similarly Pelosi P *et al*[18] found that although the delivered tidal volumes were similar in prone position, the resistance to ventilation (R_{max}) slightly increased. They also found statistically significant modifications in respiratory and chest wall resistance with a marked improvement in lung volume and oxygenation. The pulmonary mechanics g*et al*tered with the change in position due to alteration in rib cage and diaphragmatic movements. The functional residual capacity is mainly affected by the change in patient positioning, secondary to change in compliance and resistance to total respiratory system, lungs and the chest wall. Thus our study showed that cardiovascular and respiratory parameters get affected due to change in patient position from the supine position. The prone position and sitting positions showed negative haemodynamic and cardiovascular effects, while the lateral position showed improvement in the cardiovascular parameters as compared to supine position. The respiratory parameters get minimally affected in these positions if the patient is given proper surgical positioning.

CONCLUSION

We conclude that the change in patient position alters the haemodynamic parameters under anaesthesia. The prone and sitting position negatively affects 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 towards haemodynamic monitoring and fluid management is required during prone and sitting position. The respiratory parameters like minute ventilation, alveolar minute ventilation, tidal volume, dead space, peak inspiratory pressure and peak expiratory flow do not change significantly. A study involving larger number of patients would be appropriate for finding the effect of sitting position on cardio-respiratory parameters. We also found the NICO monitor to be useful and easy to use. It’s use can be recommended in patients undergoing general anaesthesia with endotracheal intubation in whom cardiac output needs to be monitored and pulmonary artery catheterization is difficult, not indicated or not available.

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