Immediate Changes in Hemodynamics and Gas Exchange after Initiation of Noninvasive Ventilation in Cardiac Surgical Patients

Abstract

Introduction: Cardiac surgery is associated with pulmonary dysfunction and complications such as prolonged intubation and reintubation. Bilevel positive airway pressure (BiPAP) machine has been used in the clinical settings to improve oxygenation, reduce work of breathing, and avoid reintubation. The effect of BiPAP on cardiovascular parameters is not well established, and very few studies have targeted hemodynamic changes. The aim of the study was to assess the immediate effect of BiPAP on respiratory and hemodynamic parameters in post-cardiac surgery patients. **Materials and Methods:** This quasi-experimental study was done on 33 adult cardiac surgery patients. Ethical review committee approval was sought and consent was taken. All patients who were in respiratory distress with respiratory rate of >30/min and/or PaO_2:FiO_2 ratio of <200 were included. Hemodynamic and respiratory parameters were recorded just before and 15 min after BiPAP application. Sample size was determined on the basis of BiPAP effect on one of the variables, PaO_2:FiO_2 ratio. **Results:** A total of 33 patients were included in the study. The average age of the patients was 60.97 ± 10.8, of which 23 (69.7%) were males and 10 (30.7%) females. BiPAP application leads to statistically significant improvement in ventilator parameters including SaO_2 29 (87.7%), PaO_2 29 (87.8%), $PaCO_2$ 21 (63.6%), and PaO_2:FiO_2 ratio in 27 (81.8%). **Conclusion:** Ventilatory parameters were significantly improved after BiPAP application in this study, but hemodynamic parameters showed no statistically significant change. BiPAP application was also able to decrease the need for reintubation in post-cardiac surgery patients.

Keywords: *Gas exchange, hemodynamics, noninvasive ventilation, oxygen*

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Introduction

Cardiac surgery is associated with pulmonary dysfunction, which can lead to postoperative complications such as prolong intubation, respiratory distress, and reintubation. The reasons for pulmonary dysfunction after cardiac surgery includes general anesthesia, surgery time, mechanical ventilation, atelectasis, fluid overload, pleural opening, lung parenchymal injury due to cardiopulmonary bypass (CPB) and microembolization, pain due to incision, chest tubes' presence, and phrenic nerve injury. Preservation of pleural integrity is associated with better respiratory function and reduced length of stay.[1] Use of left internal mammary artery in cardiac surgery is also associated with more respiratory dysfunction than only saphenous vein grafts.[2] In addition, preoperative factors such as preexisting lung diseases, smoking, old age, and poor nutritional state among others are a predisposition to complications. Respiratory dysfunction in cardiac surgical patient appears early in the postoperative period, but these changes are usually transient and respond to interventions.

Bilevel positive airway pressure (BiPAP) machine has been used in the clinical settings for patients with pulmonary edema,[3] high-risk postoperative patients, and acute hypoxemic respiratory failure. When compared with endotracheal intubation,[4] the BiPAP is more comfortable, has a role in avoiding intubations, provides better outcome (mortality and nosocomial infection), and helps in avoiding ventilator-associated complications such as ventilator-associated pneumonia and need for deep sedation. Other advantages include improved oxygenation[5,6] and decreased work of breathing which, in turn, reduces myocardial oxygen demand. It recruits atelectatic alveoli and improves lung compliance. It may also have a role in reducing the risk of nosocomial infection.

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Studies have shown that intubation and mechanical ventilation in respiratory compromised patients is associated with higher mortality,[7] and BiPAP may help in reducing such complications.[8]

BiPAP supports respiration during inspiration by applying inspiratory positive airway pressure (IPAP; which is the sum of pressure support and PEEP), and during expiration it acts like positive end-expiratory pressure by application of expiratory positive airway pressure (EPAP). It also increases PaO_2:FiO_2 ratio. Low ratio in cardiac surgical patients is associated with higher intensive care unit (ICU) mortality and pulmonary complications such as atelectasis and pulmonary edema.[9] BiPAP application improves atelectasis, and BiPAP has been used in post-cardiac surgery patients to avoid intubation. Some patients may not tolerate the mask and become restless. BiPAP may not work well in extremely agitated, uncooperative, and claustrophobic patients. In addition, it may not be beneficial in hemodynamically unstable patients and those with excessive airway secretion.

The effect of BiPAP on cardiovascular system is not very well established, and very few studies have targeted hemodynamic changes. These changes are more important for post-cardiac surgery patients who are not only recovering from the effect of cardioplegia but also having variable volume status. This is probably the only study where all important invasive and noninvasive hemodynamic parameters are considered along with ventilator parameters.

The aim of the study was to assess the immediate effect of BiPAP on respiratory and hemodynamic parameters in those post-cardiac surgery patients who require noninvasive ventilation (NIV).

Materials and Methods

This quasi-experimental study was performed on 33 adult cardiac surgery patients between the ages of 35 and 70 years. Ethical review committee approval was sought. All patients on respiratory distress were initially managed by higher FiO_2 by mask, respiratory therapy including nebulization, and prop up position. Those patients who remained in respiratory distress with respiratory rate of >30/min and PaO_2:FiO_2 ratio <200 were included in the study. BiPAP was applied as soon as the patient met these two criteria. Patient or family refusal and elective application of BiPAP were taken as exclusion criteria. Emergency surgery and preexisting pulmonary dysfunction patients were also excluded. Before initiating BiPAP, possible surgical complications such as anastomosis leakage, hemorrhage, pneumothorax, and cardiac tamponade were excluded. Decision about BiPAP application was taken by on-call resident after consultation with covering consultant of cardiac ICU (CICU). BiPAP was explained to these patients and consent was taken. For those patients who were unable to give written consent due to drowsiness or respiratory distress, it was taken from close family members (parents, spouse, and children). This decision was made after consultation with ethical review committee.

Consecutive cardiac surgical patients who fulfilled BiPAP application criteria were included in nonrandomized fashion. Sufficient communication was established with the patients, so that the procedure is well understood. BiPAP applied only to those patients who were present in CICU. Full face mask was used to cover the mouth and nose and then attached with portable BiPAP machine (VPAP III STA QuickNav; ResMed, Australia). It delivers a positive pressure through a single air circuit with the exhaled air exiting through a mask exhaust vent. Initial settings of IPAP 12 and EPAP of 6 were applied and gradually increased accordingly. No attempt was made to wean off during the study period. The patient was monitored for mask intolerance, gastric distension, and facial skin laceration.

All data were recorded on a proforma, which included demographics, reason for application, SaO_2 at the time of first application, time it started, total duration of application, initial settings, range (minimum and maximum), and outcome of BiPAP application. These data were collected by residents and consultants who were involved in patient management.

Sample size was based on the study by Takami and Ina[10] and determined on the basis of the effect on one of the variables, PaO_2:FiO_2 ratio. Changes in the hemodynamic, BiPAP parameters, SaO_2, PaO_2, $PaCO_2$, heart rate (HR), mean blood pressure (BP), central venous pressure (CVP), pulmonary artery (PA) pressure, systemic vascular resistance (SVR), and pulmonary vascular resistance (PVR) were calculated from relative changes from the baseline. A sample size of 33 achieved 90% power to detect a 20% and above mean paired difference with estimated standard deviation of the difference being 20, with a significance level (alpha) of 0.01 using a paired *t*-test.

All statistical analysis was performed using Statistical Package for the Social Sciences version 19 (SPSS Inc., Chicago, IL, USA). Frequency and percentage were computed for categorical observation, while mean and standard deviation were estimated for numeric variables. Pre- and post-BiPaP effects on dependent variables were analyzed by paired *t*-test. Repeated measure analysis of variance test was applied to observe the effect of other variables on dependent variables. A P value of less than 0.05 was considered as statistically significant.

Results

A total of 33 patients were included in the study. The average age of the patients was 60.97 ± 10.8, of which 23 (69.7%) were males and 10 (30.7%) females [Table 1]. The most common reason for BiPAP application was atelectasis (51.5%). Diagnosis was left at the discretion of CICU intensivist on the basis of X-ray findings' interpretation. Patients with pneumonia and obesity frequently required noninvasive ventilatory support. BiPAP application lead to statistically significant improvement in the following parameters: SaO_2 29 (87.7%), PaO_2 29 (87.8%), $PaCO_2$ 9 (27.3%), and PaO_2:FiO_2 ratio in 27 (81.8%). Only four patients in our study had PaO_2:FiO_2 ratio greater than 150, and of these only one patient did not show improvement in the ratio after BiPAP application [Table 2]. Only two patients required escalation of support during the study period.

Eight patients had body mass index (BMI) greater than 30. All (n = 3) patients with BMI >35 showed improvement in SaO_2, PaO_2, and PaO_2:FiO_2 ratio after BiPAP application. Nine of 17 patients who were in respiratory distress due to atelectasis needed BiPAP application for less than 24 h. BiPAP was applied preemptively on three patients soon after extubation due to low PaO_2:FiO_2 ratio on ventilator. HR reduced from mean 102 to 92 beats/min, while the mean BP was increased [Table 3]. Cardiac output which was measured after 15 min of BiPAP application also reduced from mean 4.45 ± 1.23 to 4.50 ± 1.34 L/min with a P value of 0.873.

Thirteen (36.4%) patients required BiPAP support for less than 24 h. Only one patient required reintubation in the first 24 h, and overall 6 (18.2%) patients ultimately required reintubation after prolonged BiPAP application [Table 4]. Three patients required reapplication of BiPAP within 24 h after planned removal. Four of five patients who had low PaO_2 on ventilator required BiPAP for more than 24 h.

Table 1: Demographic, Comorbid and Surgery status (n=33)

	Point estimation
Variables	
Age (Years)	60.97±10.81
Weight (kg)	75.90±17.22
Height (cm)	163.07±6.74
Body mass index (kg/m)	28.36±5.56
Gender	
Male	24 (72.7%)
Female	9 (27.3%)
Comorbid	
Hypertension	27 (81.8%)
Diabetic Mellitus	18 (54.5%)
IHD	7 (21.2%)
Other*	4 (12.1%)
Surgery	
CABG	28 (84.8%)
MVR	4 (12.1%)
Pericardiectomy	1 (3%)

Results are presented as mean±SD and n (%), Others*: CKD 2, obesity 1, AKI 1

Table 2: Reasons, Improvement and total duration of BiPAP in cardiac surgery patients (n=33)

Variables	n	%
Reason for BiPAP Application		
Pneumonia	5	15.2%
Sepsis	2	6.1%
Muscle Weakness	4	12.1%
Obesity	4	12.1%
Low PaO_2 ventilator	4	12.1%
COPD	1	3%
Pulmonary edema	1	3%
Respiratory distress due to unknown reason	2	6.1%
Respiratory distress due to atelectasis	17	51.5%
Single Reason	7	21.2%
Multiple Reasons	26	78.8%
Improvement seen in following parameters soon (15 min) after BiPAP Application		
SaO_2	25	75.8%
PaO_2	23	69.7%
$PaCO_2$	9	27.3%
Clinical Mentation, Drowsiness	7	21.2%
Reduction in respiratory rate after first app BiPAP	12	36.4%
PaO_2/FiO_2 ratio	27	81.8%
Total Duration of BiPAP		
<24 h	12	36.4%
2-3 days	19	57.6%
3-5 or above	2	6.1%

Results are presented as n (%)

Discussion

Application of alternating IPAP and EPAP improves gas exchange by recruiting atelectatic alveoli. IPAP has an additional advantage of reducing the work of breathing. In other studies, respiratory parameters were improved in 30 min, while in this study NIV has shown improvement within 15 min of application. Zoremba *et al*.[11] in their study noticed that the short-term use of BiPAP can improve pulmonary function for 24 h. It decreases the need for sedation, and the patient can protect his own airway to protect against aspiration. It also decreases nosocomial infection rate when compared with reintubation. Diaphragmatic paralysis or dysfunction, which is not uncommon in cardiac surgical patients, can be an indication for BiPAP application.[12] The other advantage includes reduced inotrope requirements and respiratory infection.[13]

Early application may have a role in reducing mortality.[14] BiPAP also has a role in reducing the need for reintubation,[15] particularly in respiratory failure patients[3] and in cardiogenic pulmonary edema[6] but does not reduce the incidence of myocardial infarction and mortality.[16] A meta-analysis by Bajaj *et al*.[17] also concluded that NIV reduces reintubation (10.8% in NIV vs. 17.8% in conventional group) in chronic obstructive pulmonary disease and high risk for extubation failure patients.

Table 3: Effect of BIPAP application on hemodynamics and ventilator parameters

	n	Pre BiPAP	Post BiPAP	*P*
Gas exchange parameters				
SaO_2	33	90[88.4, 94]	95[91,97.7]	0.003
PaO_2	33	60.2[55.7,70]	69[63.6,98.1]	0.0005
$PaCO_2$	33	44[39.05,51]	40.5[37.1,45.6]	0.005
PaO_2/FiO_2 ratio	33	107[94,137]	115[103.5,173]	0.001
Base excess	21	0.20[-0.21, 1.85]	0.30[-2.3,2.05]	0.259
Hemodynamic parameters				
HR	33	102[91,111]	92[89,108.5]	0.18
Systolic BP	33	112[104.5,128.5]	112[105,125.5]	0.443
Diastolic BP	33	63[59,83.5]	69[59,83]	0.702
Mean BP	33	79.5[70,89]	84.5[71,90.7]	0.142
CVP	32	8.5[7,10]	9[7,11]	0.062
PA pressure (Systolic)	20	32[25,37.5]	28[26,38]	0.887
PA pressure (Diastolic)	20	15[13,18]	16[14,18]	0.060
SVR	20	1259[1003,1712]	1264 [999.25,1553]	0.959
CO	14	4.45[2.60,6.25]	4.50[2.51,6.54]	0.873

Results are presented as median [25^{th}, 75^{th} percentile], Wilcoxon Signed Ranks Test

Table 4: Outcome of BiPAP Application (*n*=33)

Outcome of BiPAP Application	Number of Patients	Percentage
Re-intubation	6	18.2%
Day 1	1	
Day 2	2	
Day 3	2	
Day 4	1	
Able to maintain SaO_2 without BiPAP for 24 h	22	66.7%
BiPAP reapplication within 24 hrs. of removal	3	9.1%
Rate patient's cooperation after BiPAP application		
Fully Cooperative	30	90.90%
Reluctant to Cooperate	2	6.1%
Non Cooperate	1	3%

It may also reduce intubation rate in acute respiratory failure.[18] It reduces the reintubation rate in patients who are at high risk for postoperative pulmonary complications or have ongoing acute respiratory failure.[19] Prophylactic application is ineffective in low-risk patients, but in high-risk patient even few hours of application[20] reduces reintubation rate. Preemptive BiPAP application was applied in three patients in our study, and not only it improved oxygenation but also it prevented reintubation. BiPAP also has a role in reducing intubation rate in acute and chronic congestive heart failure (CHF) patients.[21]

BiPAP has a failure rate of 10%–55%, and the main reason is pneumonia and older age group.[22] There are various definitions of failure. For study purpose, we considered reintubation within 4 days of application as BiPAP failure and 18% patients needed reintubation in this study. Five patients in our study also had pneumonia for which BiPAP was applied. Only two patients required reintubation on day 2 of application, which showed some success, but larger studies are needed to conclude in these patients. It may be suggested not to use BiPAP in this patient population due to higher failure rate, and conventional endotracheal intubation must be preferred.[23] Age of the patients seems to have no effect on failure rate in this study.

There was a statistically significant improvement in PaO_2 within 15 min of application. It was more effective in 93% of patients in whom PaO_2 was lower than 60 mmHg (14/15). BiPAP improves oxygenation more rapidly than continuous positive airway pressure in cardiogenic pulmonary edema patients.[3]

It usually increases SaO_2 without significant changes in $PaCO_2$[24] in normal patients. But in patients with hypercapnia, its role is different. In our study, BiPAP application significantly reduces $PaCO_2$ in 21 (63%) patients. BiPAP seems to be more efficient in patients with hypercapnia as we have seen in our study that most of the patients (11 of 14) whose $PaCO_2$ was higher than 45 mmHg showed reduction in $PaCO_2$ within 15 min of BiPAP application. Our results are similar to other studies carried out earlier, which also showed a significant effect of BiPAP only in patients with hypercapnia.[6,25] Mehta *et al*. showed improvement in $PaCO_2$ after BiPAP application, but it increases acute myocardial infarction rate (71%).[26] Tobias[5] also demonstrated reduction in respiratory rate and $PaCO_2$ in postoperative patients. Those patients were in impending respiratory failure, and application of BiPAP improved oxygenation and CO_2 levels and avoided reintubation.

We took PaO_2:FiO_2 ratio of <200 as an inclusion criteria, and BiPAP application did improve the ratio significantly. The average value of ratio before and after application was 107 versus 115. This increase in ratio reached more than 200 only in five (15.1%) patients. The reason may be that most of our patients (n = 29) had less than 150 ratio before BiPAP application. One of the study also used this ratio for indication[10] and the ratio increased significantly within 3 min. Park *et al*.[6] also showed improvement in the ratio within 10 min of application and required more than 30 min to reach 200 level but those were pulmonary edema patients.

Hemodynamic effects are varied according to the disease state and also on the IPAP and EPAP settings and the type of mask (nasal vs. face). In normal patients, it may decrease CO, while in chronic heart failure patients it may improve CO by reducing SVR[27] and preload. Cardiac function improved in distended heart but not in normal functioning heart. No significant hemodynamic changes were seen after BiPAP application during the initial 15 min. It may be inferred that it needed more time for hemodynamic improvement or it may be more effective in pulmonary edema cases as studies have shown a reduction in HR and SVR after BiPAP application in pulmonary edema patients. BiPAP reduces sympathetic activity,[28] preload, and afterload leading to enhanced ventricular function. Mean arterial pressure (MAP), CVP, and PA diastolic pressures slightly increase probably due to an increase in intrathoracic pressure exerted by BiPAP.[29] Insignificant reduction in HR and PA systolic pressure was seen in our patients. Decrease in HR occurs due to parasympathetic stimulation by stretched receptors in lungs. This is in contrast to a previous study in post-cardiac surgery patients by Kilic *et al*. which showed a slight increase in HR at 1 h along with a decrease in MAP. These values remain insignificant even after 12 h of BiPAP application. Cardiac surgery patients are usually in various stages of hemodynamic status; some may be hypovolemic or hypervolumic, while others may still be recovering from the effect of cardioplegia. In addition, hemodynamics are also affected by postoperative cardiac index, pain, BiPAP settings, and patient's cooperation. Significant HR reduction was seen in two previous studies, but those were with patients CHF and the improvement was seen after 30 min.[26,30] This change in HR in patients with pulmonary edema was significant within 10 min of application in a study by Marcelo *et al*. Although CO was increased in our patients, it was insignificant. The increase in CO and MAP was probably due to reduction in preload and improved cardiac contractility after BiPAP. Another study which is comparable to this study showed improvement in cardiac index(CI) without changes in systemic and PA pressures.[15] Atelectasis and overinflation of lung above functional residual capacity (FRC) can increase PVR. Takami and Ina showed higher systemic vascular resistance index and pulmonary arterial resistance index along with low CI in those patients who required BiPAP when compared with non-BiPAP patients. It will be interesting to see the changes in ionotropes and vasopressors' requirement in future studies. Another limitation relates to heterogeneity of the study subset unknown baseline respiratory function (we try to exclude these patients), different types of surgical procedures, CPB time, and length of postoperative ventilation. Although the most common mode for weaning at our institute is SIMV, it would have been ideal to standardize the weaning mode in all study patients.

Hypoxemia, atelectasis, and respiratory impairment are more common in obese cardiac surgery patients, and short-term use of BiPAP was able to improve pulmonary functions which lasted for about 24 h after discontinuation. It is recommended to commence BiPAP early to achieve maximum benefits. This study also showed improvement in respiratory parameters in obese patients,[22] particularly in patients with BMI greater than 35. There is a suggestion to apply BiPAP, soon after extubation in all patients with higher BMI. Prophylactic BiPAP also has a role in patients with low ejection fraction where it reduces the incidence of atelectasis and at the same time increase PaO_2.[31] BiPAP can be used as a part of fast-track extubation. As a weaning mode, it reduces extubation time when compared with intermittent mandatory ventilation.[32]

Conclusion

Saturation, PaO_2, $PaCO_2$, and PaO_2:FiO_2 ratios were significantly improved soon after BiPAP application in this study, but no statistically significant changes were seen in hemodynamic parameters. BiPAP application was also able to reduce the need for reintubation in post-cardiac surgery patients.

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Conflicts of interest

There are no conflicts of interest.

References

1. Oz BS, Iyem H, Akay HT, Yildirim V, Karabacak K, Bolcal C, *et al*. Preservation of pleural integrity during coronary artery bypass surgery affects respiratory functions and postoperative pain: A prospective study. Can Respir J 2006;13:145-9.
2. Cohen AJ, Moore P, Jones C, Miner TJ, Carter WR, Zurcher RP, *et al*. Effect of internal mammary harvest on postoperative pain and pulmonary function. Ann Thorac Surg 1993;56:1107-9.
3. Stoltzfus S. The role of noninvasive ventilation: CPAP and BiPAP in the treatment of congestive heart failure. Dimens Crit Care Nurs 2006;25:66-70.
4. Joshi G, Tobias JD. A five-year experience with the use of BiPAP in a pediatric intensive care unit population. J Intensive Care Med 2007;22:38-43.
5. Tobias JD. Noninvasive ventilation using bilevel positive airway pressure to treat impending respiratory failure in the postanesthesia care unit. J Clin Anesth 2000;12:409-12.
6. Park M, Sangean MC, Volpe Mde S, Feltrim MI, Nozawa E, Leite PF, *et al*. Randomized, prospective trial of oxygen, continuous positive airway pressure, and bilevel positive airway pressure by face mask in acute cardiogenic pulmonary edema. Crit Care Med 2004;32:2407-15.
7. Jaber S, De Jong A, Castagnoli A, Futier E, Chanques G. Non-invasive ventilation after surgery. Ann Fr Anesth Reanim 2014;33:487-91.
8. Hess DR. Noninvasive positive-pressure ventilation and ventilator-associated pneumonia. Respir Care 2005;50:924-9; discussion 929-31.
9. Esteve F, Lopez-Delgado JC, Javierre C, Skaltsa K, Carrio ML, Rodriguez-Castro D, *et al*. Evaluation of the PaO2/FiO2 ratio after cardiac surgery as a predictor of outcome during hospital stay. BMC Anesthesiol 2014;14:83.
10. Takami Y, Ina H. Beneficial effects of bilevel positive airway pressure after surgery under cardiopulmonary bypass. Interact Cardiovasc Thorac Surg 2003;2:156-9.
11. Zoremba M, Kalmus G, Begemann D, Eberhart L, Zoremba N, Wulf H, *et al*. Short term non-invasive ventilation post-surgery improves arterial blood-gases in obese subjects compared to supplemental oxygen delivery – A randomized controlled trial. BMC Anesthesiol 2011;11:10.
12. Blanco M, Ernst G, Salvado A, Cambursano VH, Borsini E. Non-invasive ventilation in patients with diaphragmatic paralysis. Case report. Rev Fac Cien Med Univ Nac Cordoba 2017;74:55-9.
13. Boeken U, Schurr P, Kurt M, Feindt P, Lichtenberg A. Early reintubation after cardiac operations: Impact of nasal continuous positive airway pressure (nCPAP) and noninvasive positive pressure ventilation (NPPV). Thorac Cardiovasc Surg 2010;58:398-402.
14. Landoni G, Augoustides JG, Guarracino F, Santini F, Ponschab M, Pasero D, *et al*. Mortality reduction in cardiac anesthesia and intensive care: Results of the first international consensus conference. Acta Anaesthesiol Scand 2011;55:259-66.
15. Hoffmann B, Jepsen M, Hachenberg T, Huth C, Welte T. Cardiopulmonary effects of non-invasive positive pressure ventilation (NPPV) – A controlled, prospective study. Thorac Cardiovasc Surg 2003;51:142-6.
16. Weng CL, Zhao YT, Liu QH, Fu CJ, Sun F, Ma YL, *et al*. Meta-analysis: Noninvasive ventilation in acute cardiogenic pulmonary edema. Ann Intern Med 2010;152:590-600.
17. Bajaj A, Rathor P, Sehgal V, Shetty A. Efficacy of noninvasive ventilation after planned extubation: A systematic review and meta-analysis of randomized controlled trials. Heart Lung 2015;44:150-7.
18. Liu YJ, Zhao J, Tang H. Non-invasive ventilation in acute respiratory failure: A meta-analysis. Clin Med (Lond) 2016;16:514-23.
19. Olper L, Corbetta D, Cabrini L, Landoni G, Zangrillo A. Effects of non-invasive ventilation on reintubation rate: A systematic review and meta-analysis of randomised studies of patients undergoing cardiothoracic surgery. Crit Care Resusc 2013;15:220-7.
20. Fagevik Olsen M, Wennberg E, Johnsson E, Josefson K, Lonroth H, Lundell L. Randomized clinical study of the prevention of pulmonary complications after thoracoabdominal resection by two different breathing techniques. Br J Surg 2002;89:1228-34.
21. Levitt MA. A prospective, randomized trial of BiPAP in severe acute congestive heart failure. J Emerg Med 2001;21:363-9.
22. Cabrini L, Plumari VP, Nobile L, Olper L, Pasin L, Bocchino S, *et al*. Non-invasive ventilation in cardiac surgery: A concise review. Heart Lung Vessel 2013;5:137-41.
23. De Santo LS, Bancone C, Santarpino G, Romano G, Della Corte A, Vicchio M, *et al*. Noninvasive positive-pressure ventilation for extubation failure after cardiac surgery: Pilot safety evaluation. J Thorac Cardiovasc Surg 2009;137:342-6.
24. Yaglioglu H, Koksal GM, Erbabacan E, Ekici B. Comparison and evaluation of the effects of administration of postoperative non-invasive mechanical ventilation methods (CPAP and BIPAP) on respiratory mechanics and gas exchange in patients undergoing abdominal surgery. Turk J Anaesthesiol Reanim 2016;43:246-52.
25. Masip J, Betbese AJ, Paez J, Vecilla F, Canizares R, Padro J, *et al*. Non-invasive pressure support ventilation versus conventional oxygen therapy in acute cardiogenic pulmonary oedema: A randomised trial. Lancet 2000;356:2126-32.
26. Mehta S, Jay GD, Woolard RH, Hipona RA, Connolly EM, Cimini DM, *et al*. Randomized, prospective trial of bilevel versus continuous positive airway pressure in acute pulmonary edema. Crit Care Med 1997;25:620-8.
27. Acosta B, DiBenedetto R, Rahimi A, Acosta MF, Cuadra O, Van Nguyen A, *et al*. Hemodynamic effects of noninvasive bilevel positive airway pressure on patients with chronic congestive heart failure with systolic dysfunction. Chest 2000;118:1004-9.
28. Haarmann H, Folle J, Nguyen XP, Herrmann P, Heusser K, Hasenfuss G, *et al*. Impact of non-invasive ventilation on sympathetic nerve activity in chronic obstructive pulmonary disease. Lung 2016;195:69-75.
29. Matte P, Jacquet L, Van Dyck M, Goenen M. Effects of conventional physiotherapy, continuous positive airway pressure and non-invasive ventilatory support with bilevel positive airway pressure after coronary artery bypass grafting. Acta Anaesthesiol Scand 2000;44:75-81.
30. Nava S, Carbone G, DiBattista N, Bellone A, Baiardi P, Cosentini R, *et al*. Noninvasive ventilation in cardiogenic pulmonary edema: A multicenter randomized trial. Am J Respir Crit Care Med 2003;168:1432-7.
31. Lopes CR, Brandao CM, Nozawa E, Auler JO Jr. Benefits of non-invasive ventilation after extubation in the postoperative period of heart surgery. Rev Bras Cir Cardiovasc 2008;23:344-50.
32. Rathgeber J, Schorn B, Falk V, Kazmaier S, Spiegel T, Burchardi H. The influence of controlled mandatory ventilation (CMV), intermittent mandatory ventilation (IMV) and biphasic intermittent positive airway pressure (BIPAP) on duration of intubation and consumption of analgesics and sedatives. A prospective analysis in 596 patients following adult cardiac surgery. Eur J Anaesthesiol 1997;14:576-82.