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Complete Closed-Loop Ventilatory Circuit Delays the Onset of Ventilator-Associated Pneumonia in Mechanically Ventilated Neurological Patients in the ICU: A Single-Center Prospective Preliminary Study

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Abstract

Background Ventilator-associated pneumonia (VAP) is preventable yet its incidence remains high. We compared conventional ventilator circuit with open suction and dual heated wire circuit (DHWC) with closed suction on the incidence of VAP.

Methods This is a single-center, prospective cohort study conducted at a tertiary care hospital in neurological patients admitted to the neuro-intensive care unit (neuro-ICU) and requiring mechanical ventilation (MV) for more than 48 hours. Patients were ventilated using either conventional ventilator circuit with open suction (open group) or DHWC with closed suction (closed group) and were observed for VAP during the first 14 days of MV. The incidence and day of onset of VAP, duration of MV, duration of neuro-ICU and hospital stay, and mortality was noted in each group.

Results A total of 63 patients were included (32 in open and 31 in closed group). The incidence of VAP was 9.3% in the open group and 12.9% in the closed group ($p = 0.8$). All the patients developed late VAP, that is, >96 hours after intubation. However, as compared to the open group, VAP was observed much later in the closed group (day 7 vs. day 11). Duration of MV, neuro-ICU stay, hospital stay, and mortality did not differ significantly.

Conclusion In this study, VAP incidences are similar in both the groups. However, neurological patients requiring MV for a short period might benefit from the usage of DHWC with closed suction system as VAP was seen to occur later in this group. Further, a randomized controlled trial with larger sample size is desired to confirm our findings.

Keywords
- dual heated wire circuit
- closed suction system
- open suction system
- neurological illness
- ventilator-associated pneumonia

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Introduction

Ventilation is an essential mode of intervention in the management of patients with neurological illnesses requiring intensive care unit (ICU) management. Ventilator-associated pneumonia (VAP), observed after 48 hours of invasive mechanical ventilation (MV), remains one of the most common nosocomial infections in patients receiving MV.[1] The likelihood of VAP increases up to 21 times with MV.[2] The incidence of VAP is tremendously influenced by the characteristics of the patient population, preventive techniques, and diagnostic criteria used.[1]

The available data regarding the health care-associated infections in patients admitted to medical and surgical ICU cannot be extrapolated to neurological patients as they may have altered mental status or motor disability and are at a greater risk of developing pneumonia. However, very few studies are available for VAP in neurological patients.[2]

Neurological patients are commonly intubated to protect the airway and require prolonged MV which predisposes them to a higher risk of VAP.[3] VAP can delay the weaning process, prolong the duration of MV and ICU/hospital stay, and doubles the risk of mortality which in turn can impose a substantial financial burden on the patients and the health care system.[1] The occurrence of VAP is preventable and an appropriate approach decreases the cost of hospitalization, limits the duration of hospital stay, and reduces morbidity and mortality.[4] The type of humidification system, ventilatory circuits, and suction systems used during MV can influence the incidence of VAP.[5]

Our study aimed to observe the incidence of VAP with open and closed breathing systems. There are many studies assessing the incidence of VAP with closed suction system and heated wire circuits individually. However, till date there are no studies assessing the effectiveness of combining both of them and creating a totally closed system of breathing circuit. The primary objective of our study was to compare the incidence of VAP using conventional ventilator circuits with open suction (open group) and dual heated wire circuits (DHWCs) with closed suction (closed group) in patients ventilated for neurological illnesses. We hypothesized that the type of breathing system will affect the VAP incidence. The secondary objectives were to compare the outcome in terms of duration of MV, ICU stay, hospital stay, and in-hospital mortality.

Materials and Methods

This was a prospective study conducted at a tertiary care center in Southern India, from June 2019 to November 2020, in patients admitted to the neuro-ICU. All adult patients (18–75 years) with neurological illnesses requiring MV for more than 48 hours were included. Patients diagnosed with pneumonia before or within 48 hours of intubation, intubated for more than 12 hours before admission to ICU, intubated in other hospital or following cardiorespiratory arrest, and reintubated during the study period for reasons other than endotracheal tube blockage were excluded from the study. Patients meeting the inclusion criteria were recruited in the study after obtaining written informed consent and institute ethics approval (NIMH/DO/IEC (BS & NS DIV)/2018-2019 dated 30.05.2019) and trial registration (CTRI/2019/08/020621). The ventilators in the ICU were equipped with two types of humidifier systems, MR810 and MR850 (Fisher and Paykel). The MR810 humidifier system includes MR810 heated humidifier (HH), MR370 autofill chamber, and is compatible with the conventional disposable breathing circuit, which are not actively heated, requiring water traps. The MR850 system includes MR850 HH, MR290 autofill chamber, and RT380 DHWC with temperature probes at chamber outlet and Y piece. This system facilitates provision of heated and humidified gases at a temperature of 37°C, and prevents condensation of the gases within the circuit through active heating of the inspiratory and expiratory limbs of the breathing circuits and thus the need to disconnect the breathing circuit to empty the water condensate is curtailed. Tracheal suction system used was open suction with MR810 humidifier system as it was an open loop breathing system whereas closed tracheal suction system was used with MR850 to maintain the benefit of closed loop. The patients were divided into two groups, based on the ventilator with the available humidifier system they received at the time of the admission to the neuro-ICU.

Open group (open-loop breathing system): Participants in whom MR810 HH and conventional disposable circuit with water traps were used along with the open tracheal suction system.

Closed group (closed-loop breathing system): Participants in whom MR850 humidifier system with DHWC, along with closed tracheal suction system was used (►**Fig. 1**).

Humidifiers in both groups were set at 37°C. Conventional circuits were changed once in 3 days and the DHWC was used for 14 days. The closed suction system was changed once in every 3 days. Diagnosis of VAP was done based on the Centre for Disease (CDC) PNU 2 definition which included positive signs/symptoms/laboratory parameters along with imaging and microbiological (endotracheal tube aspirate) evidence.[6]

At enrolment in the ICU, baseline variables, that is, age, gender, diagnosis, Acute Physiology and Chronic Health Evaluation score II, Glasgow Coma Score, and biochemistry were noted. On the second day complete blood count, chest X-ray, and arterial blood gas were done and endotracheal aspirate for culture and sensitivity was sent to rule out the preexisting pneumonia. Patients were screened for the presence of clinical VAP daily after 48 hours of intubation. Tracheal aspirate cultures were repeated when there was a change in quantity and characteristics of secretions or on clinical suspicion of VAP. Other investigations were at the discretion of the ICU physician. Incidence of early (within 4 days of MV)/late (after 4 days of MV) VAP and clinical and microbiological VAP were noted in both groups. Daily follow-up was conducted till the diagnosis of VAP as per CDC PNE 2 definition or till 14 days of MV or extubation whichever was earlier. In both groups, VAP prevention care bundles were observed which included elevation of head end of the bed by 30 to 45 degrees, stress ulcer prophylaxis, use of nasogastric tube, early enteral nutrition, maintenance of cuff pressure between 25 and 30 cm H2O, deep vein thrombosis

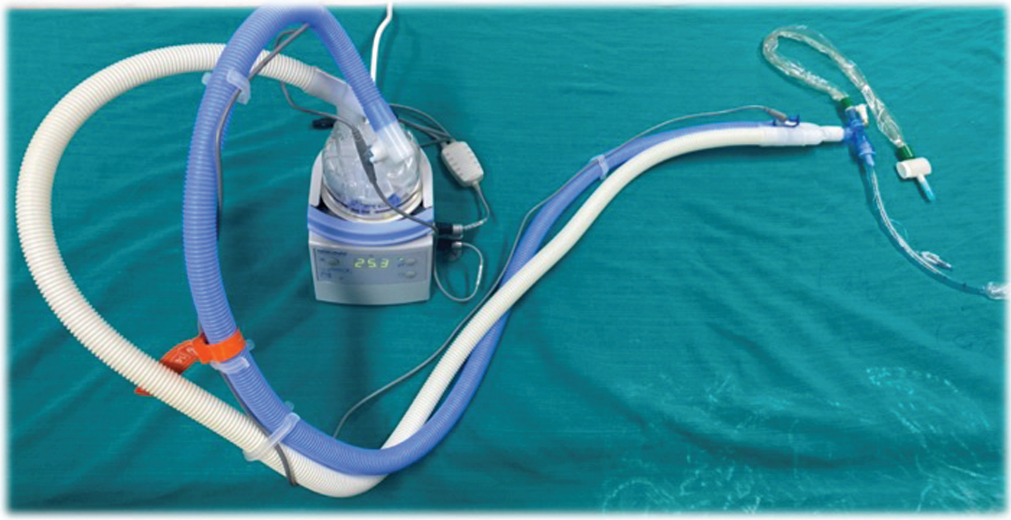

Fig. 1 The closed-loop breathing system showing MR850 humidifier system, dual heated wire circuit (DHWC) with inspiratory limb (blue in color) and the expiratory limb (white in color), along with closed tracheal suction system connected to the endotracheal tube.

prophylaxis, and daily sedation interruption and spontaneous breath trials. Incidence of endotracheal tube occlusion requiring reintubation was recorded. Patient requiring tracheostomy and the day at which it was performed was noted down. The use of nebulizer therapy and transport of the patient outside the ICU were noted. Patients requiring plasmapheresis, blood transfusion, immunosuppressant drugs, steroids, antibiotics, antiepileptics, and other medications were noted.

Based on the Indian literature, at the tertiary care center ICU which included neuro-medical patients, the reported VAP incidence was 78%.[7] Another study reported 57.14% of VAP incidence which found to increase to 76% in trauma cases and 85.1% in patients requiring MV > 15 days.[8] Based on this literature, we assumed VAP incidence of 60% in our neuro-medical cases and aimed to reduce it to 30%, and with a study power of 80% and a type 1 error rate of 5%, the calculated sample size for each group was 42. As we did not have the recent incidence of nosocomial pneumonia for our ICU, we used the incidence from the Indian literature. Quantitative data were presented as mean ± standard deviation or as median and interquartile range, while qualitative data were expressed as frequency or percentage. The collected data were tabulated, and statistical analysis was performed using the R-Ver software. To assess the normality of the data, the Shapiro–Wilk test was employed. For normally distributed data, Student's *t*-test and chi-square test were used, while nonparametric tests such as the Mann–Whitney *U* test and Fischer's test were applied for non-normally distributed data, as appropriate. A significance level of $p < 0.05$ was considered statistically significant.

Results

The study involved the comparison of two groups, open and closed, comprising 32 and 31 patients, respectively (►**Fig. 2**). The baseline characteristics of both groups were found to be comparable (►**Table 1**). Among the 63 patients, 7 developed VAP, resulting in an overall incidence of 11.1% and a VAP rate of 9.8 per 1,000 ventilator days. The incidence of VAP in the open group was 9.3% (3 of 32 patients), and in the closed group, it was 12.9% (4 of 31 patients), with no statistically significant difference between the groups ($p = 0.8$). Also, the mean duration of MV, ICU stay, hospital stay, and mortality in ICU or in-hospital was not statistically significant between the groups (►**Table 2**).

None of the patients in either group developed early VAP. The VAP was observed to be of late onset in all the patients with a median of 7 days in the open group (2 patients on day 7 and 1 at day 11) and 11 days in the closed group (1 patient at day 7, 2 patients at day 11, and fourth patient at day 12) (►**Table 2**). Thus, VAP was seen to occur later in the closed group as compared to the open group. On microbiological assessment, most common microbiological isolate on culture was *Klebsiella pneumoniae*; 2 in each group, followed by *Acinetobacter baumannii*; 1 in open group versus 2 in closed group. All isolates were multidrug-resistant except an Acinetobacter strain in closed group which was sensitive to most of the antimicrobials. On comparing various parameters among the patients who did and did not develop VAP, the only significant difference observed was in the hemoglobin level at the time of admission (►**Table 3**).

Discussion

In the existing literature, the incidence of VAP has been reported in the wide range of 5 to 78%.[7–10] This disparity to a certain extent could be attributed to the different VAP definitions and different ICU setups with heterogeneous patient conditions such as medical, surgical, neurological, etc., which may have affected the reported VAP incidence.

In a surveillance study conducted in a neurological ICU which included both neurological and neurosurgical cases, the incidence of VAP was 11.7%.[11] In another study which

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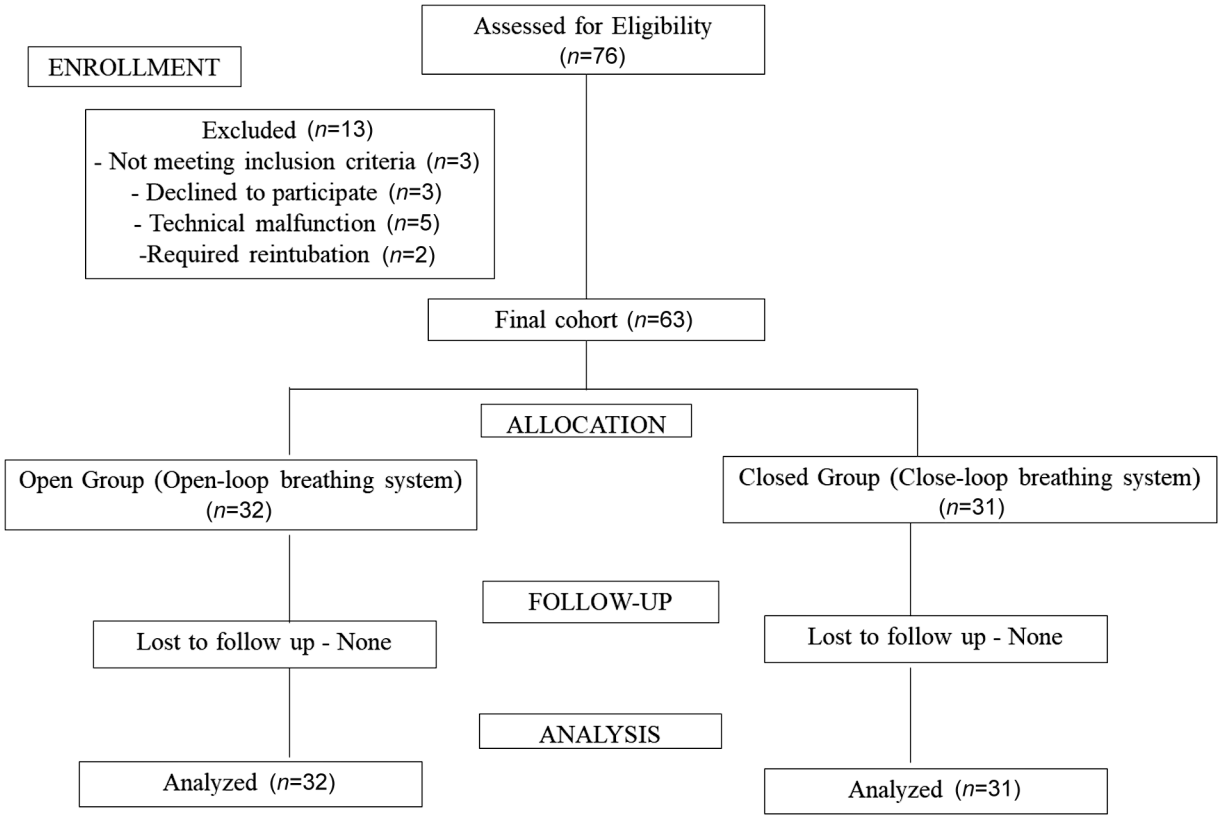

Fig. 2 The study flow diagram as per to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.

Table1 Demographic and clinical variables of the patients in the two groups

Variable	Open group ($n=32$)	Closed group ($n=31$)	*p*-Value
Age (y)	39.5 ± 13	35.2 ± 14.8	0.17
Gender (male:female)	21:11	18:13	0.72
Height (cm)	162 ± 5.6	160 ± 6.4	0.44
Weight (kg)	65.2 ± 9.7	64.5 ± 9.5	0.60
Smokers (yes:no)	11:21	8:23	0.64
APACHE II score	9.5 (5.75–12)	9 (6–11)	0.67
GCS-M	5 (5–6)	5 (5–6)	0.97
Comorbidities			0.35
HTN	13 (40%)	6 (19%)	
DM	5 (15%)	3 (9%)	
BA	1 (3%)	1 (3%)	
IHD	1 (3%)	3 (10%)	
Diagnosis			0.99
GBS	11 (34%)	11 (35%)	
MG	1 (3%)	1 (3%)	
Meningitis/encephalitis	5 (15%)	4 (13%)	
CVA	14 (43%)	13 (41%)	
Dermatomyositis	1 (3%)	1 (3%)	

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Table1 (*Continued*)

Variable	Open group ($n = 32$)	Closed group ($n = 31$)	*p*-Value
Bulbar palsy	9 (28.13%)	13 (41.90%)	0.37
Quadriparesis	13 (40.63%)	16 (51.61%)	0.53
Tracheostomy (yes:no)	9:23	8:23	1
Day of tracheostomy	12 (8–17)	15 (8.75–18.5)	0.63

Abbreviations: APACHE II score, Acute Physiology and Chronic Health Evaluation score; BA, bronchial asthma, CVA, cerebrovascular accident; DM, diabetes mellitus; GBS, Guillain–Barre syndrome; GCS-M, Glasgow Coma Motor Score; HTN, hypertension; IHD, ischemic heart disease; MG, myasthenia gravis.
Note: Variables expressed as mean ± standard deviation (SD) – age, height, weight. Variables expressed as median (interquartile range) – APACHE II score, GCS-M. Variables expressed as number (percentage) – comorbidities, diagnosis, bulbar palsy, and quadriparesis.

Table 2 Comparison of the primary and the secondary outcomes in the two groups

Outcome variable	Open group ($n = 32$)	Closed group ($n = 31$)	*p*-Value
VAP incidence	3 (9.3%)	4 (12.9%)	0.8
Day of onset of VAP	7 (7–11)	11 (7–12)	0.96
Duration of MV (d)	13 (9–17)	18.5 (7–27.75)	0.57
Duration of ICU stay (d)	16 (10–19.75)	21.5 (9.25–33.25)	0.46
Duration of hospital stay (d)	24 (18.25–39)	29 (17–50)	0.65
ICU mortality	2 (6.2%)	3 (9.6%)	0.96
Hospital mortality	3 (9.3%)	3 (9.6%)	0.98

Abbreviations: ICU, intensive care unit; MV, mechanical ventilation; VAP, ventilator-associated pneumonia.
Note: Variables expressed as median (interquartile range) – duration of MV, ICU stay, and hospital stay. Variables expressed as number (percentage) – VAP incidence, ICU mortality, and hospital mortality.

Table 3 Comparison of clinical variables between the patients who did and did not develop VAP

Variable	No VAP ($n = 56$)	VAP ($n = 7$)	*p*-Value
Age (y)	37.4 ± 13.96	37.2 ± 15.6	0.82
Gender (male/female)	36:20	4:3	0.49
Height (cm)	161.6 ± 5.8	159.2 ± 7.8	0.37
Weight (kg)	65.16 ± 9.54	62.85 ± 10.69	0.58
APACHE score	9 (6–11)	10 (8.5–12)	0.38
GCS-M	5 (5–6)	5 (5–5.5)	0.64
Hb at admission (g/dL)	13.25 (11.28–14.9)	11.6 (10.75–12.25)	**0.05**
TLC at admission (TLC/uL)	11,650 (9,800–15,700)	12,400 (10,600–12,750)	1
RBS at admission (mg/dL)	138.3 ± 55.3	170.1 ± 96.2	0.30
Duration of MV	12 (7–27)	17 (14.5–23.5)	0.36
Duration of ICU stay	17 (9–28)	21 (17–27.5)	0.34
Duration of hospital stay	25 (16.75–42.75)	47 (28.5–52)	0.21
Quadriparesis	26 (46.43%)	3 (42.86%)	0.99
Bulbar palsy	19 (33.93%)	3 (42.86%)	0.96
Transport out of ICU	23 (41%)	4 (57.14%)	0.68

(*Continued*)

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Table 3 (*Continued*)

Variable	No VAP ($n = 56$)	VAP ($n = 7$)	*p*-Value
Comorbid conditions	24 (42.86%)	1 (14.29%)	0.29
Steroids	16 (28.57%)	2 (28.57%)	1
Immunosuppressants	6 (10.7%)	0	0.81
Blood transfusion	41 (73.2 %)	4 (57.14%)	0.65
Reintubation	5 (8.93%)	1 (14.29%)	0.69

Abbreviations: APACHE II score, Acute Physiology and Chronic Health Evaluation score; GCS-M, Glasgow Coma Motor Score; Hb, hemoglobin; ICU, intensive care unit; TLC, total leucocyte count; RBS, random blood sugar; MV, mechanical ventilation; VAP, ventilator-associated pneumonia.
Note: Variables expressed as mean ± standard deviation (SD) – age, height, weight, and RBS. Variables expressed as median (interquartile range) – APACHE II score, GCS-M, Hb, TLC, days from admission to ICU, days from admission to Intubation, duration of MV, duration of ICU stay, and duration of hospital stay. Variables expressed as number (percentage) – quadriparesis, bulbar palsy, comorbid conditions, transport out of ICU, use of steroids, use of immunosuppressants, blood transfusion, and reintubation.

again included both neurological and neurosurgical ICU patients, authors reported a 24% incidence of VAP.[2] Whereas Josephson et al found the incidence of VAP to be 4.1% in the neurovascular subset of neurological patients admitted to the neurocritical care unit.[3] In our study, which included only a neurological subset of patients, we found the overall incidence of VAP to be 11.1% (7 out of 63 patients), and the VAP rate to be 9.8 for 1,000 ventilator days.

Studies concerning VAP prevention strategies, hypothesizing that reducing the exposure of the patient's airway to environmental contamination, have shown conflicting results with only a few studies showing a reduction in the incidence of VAP. Strategies to prevent VAP included different humidification systems, ventilatory circuits, and tracheal suction systems, where the use of a heated wire ventilatory circuit and closed suction system were expected to reduce the accumulated potentially contaminated condensate, thereby reducing the need to disconnect the circuit to empty it, and avoiding opening of the breathing system for suctioning out secretions, respectively. Thereby, minimizing cross-contamination from the extraneous environment and the caregivers, might reduce the occurrence of VAP.[5]

Lorente et al conducted a randomized controlled trial comparing the use of passive (heat moisture exchange [HME]) and active humidifiers (HH, with dual limb heated circuits) on the incidence of VAP.[12] They observed a significantly lower incidence of VAP with the use of HH compared to HME (15.69% vs. 39.62%, $p = 0.006$). They credited this reduction of VAP incidence to decreased formation of circuit condensate reducing frequent breaks in the circuit, thereby reducing the possible access of exogenous microorganisms into the circuit. Boots et al conducted a similar study comparing hygroscopic HME with a bacterial viral filter with hot-water humidification with a heated wire in both inspiratory and expiratory circuit limbs (double heated wire [DHW]) or the inspiratory limb only (single heated wire [SHW]) on the incidence of VAP.[13] Contrary to the findings of Lorente et al, in this study the occurrence of VAP was found to be similar in all the groups (13% in HME, 14% in DHW, and 10% in the SHW group, $p = 0.61$). Our study too, which compared a conventional disposable breathing circuit with water traps, a HH, and an open tracheal suction system against the DHWC breathing circuit with a HH and closed suction system, we did not observe a difference in the VAP incidence (9.3% vs. 12.9%, $p = 0.8$). In our study, in addition to the DHWC, we used closed suction to maintain the closed-loop breathing system which was compared against the open breathing system.

Further, we observed late onset of VAP (> 96 hours) in all the patients, more so in patients with closed breathing systems (mean of day 7 vs. day 11). This suggests closed breathing circuit weigh benefit in patients who may require short-term ventilation (< 7 days) and may be helpful to circumvent VAP, especially during the initial days of MV when the risk of VAP is maximum.[3] Neurological patients with normal lungs who are intubated for protection of the airway due to decreased sensorium might require MV for a shorter period until the improvement of neurological illness. In this subset of patients, the usage of a closed breathing system might prevent the occurrence of VAP altogether. Another interpretation of this finding could be the use of a closed breathing system in patients requiring prolonged ventilation, this delay in the VAP onset might be beneficial as it may decrease the number of VAP episodes. We have not evaluated the number of episodes of VAP as the patients were not followed through the hospital stay.

On comparing open versus closed tracheal suction systems, Alipour et al in their study found a lower incidence of VAP in the closed system compared to an open system ($p = 0.016$).[14] David et al in their study which included 200 patients receiving MV observed decreased incidence of VAP with closed suction, especially in delayed VAP.[15] Ardehali et al in a similar study did not find a significant difference in the occurrence of VAP between the two groups (20 % in the open group and 16.7 % in the closed group with $p = 0.637$).[16] In a recent meta-analysis, comparing open versus closed suction systems for VAP prevention, the open suction system was found to be associated with a higher frequency of VAP.[17] However, in general, and specifically in neuro-ICU, there is a paucity of literature comparing the effect of different ventilatory circuits (conventional/single heated/dual heated ventilatory circuits) with or without closed tracheal suction systems on the incidence of VAP.

As reported in literature, in this study too, the most common organism isolated in VAP was multidrug-resistant Gram-negative bacilli, that is, *K. pneumoniae* followed by *A. baumannii*.[18–20]

We acknowledge a few limitations of the present study. First, we lacked the recent information regarding the incidence of nosocomial pneumonia for our ICU, the availability of the same would have given more realistic estimation of the sample size. Second, the sample size could not be met as the cases recruitment was affected due to the coronavirus pandemic. Third, the incidence of VAP was lower in our study, and considering this to prove the difference between the groups would have required a much higher sample size. Thus, in the future, a randomized controlled study with larger sample size is desired. However, the strength of our study is this is the first study assessing the effectiveness of combining heated dual wire circuit with closed suction system (i.e., complete closed-loop breathing system).

Conclusion

In this observational study conducted at a neurological ICU at a tertiary care center, the observed incidence of VAP was 11.1% and the VAP rate was 9.8 for 1,000 ventilator days. The incidence of VAP did not differ with the use of a closed-loop (DHWC along with closed suction) as compared to open-loop (conventional circuit with open suction) breathing system. All the patients developed late-onset VAP only. And with a closed-loop, the onset was much more delayed (11 vs. 7 days). Thus, neurological patients requiring MV for a short period might benefit from the usage of a dual limb heated ventilator circuit with a closed suction system, thereby having the potential to avoid the occurrence of VAP. We did not observe any difference in the duration of MV, ICU and hospital stay, or in-hospital mortality. However, a randomized controlled trial with a higher sample size is required to confirm our preliminary findings.

Conflict of Interest
None declared.

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