Original Article

Utility of Bain's Circuit to Deliver Respiratory Support in a Resource-Limited Setting during the COVID-19 Pandemic

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Abstract

Introduction: Patients with COVID pneumonia, who did not respond to high-flow oxygen by nonrebreathing mask (NRBM), needed additional support to deliver oxygen with pressure. We present our innovation to use Bain's circuit to deliver continuous positive airway pressure (CPAP) along with 100% oxygen in patients with COVID-19 when there was a shortage of respiratory support equipment. **Materials and Methods:** It is a retrospective observational study conducted at two high-volume, government-designated, tertiary level COVID centers of Northern India, during May and June 2021. After taking informed consent from all patients included in the study, a nonventilated noninvasive ventilation (NIV) mask was used as the interface between Bain's circuit and the patient for making a tight seal. Vital parameters were recorded on admission, before putting the patient on Bain's circuit, at 30 min, and 6 h after the initiation of Bain's circuit. **Results:** Forty-five patients were enrolled in this study. There was a significant reduction in the work of breathing after the application of Bain's circuit. Vital parameters show improvement of the condition. Sensorium also showed a significant improvement after the application of Bain's circuit. Overall, 40% of patients who received Bain's circuit were weaned off to oxygen by NRBM, 31.1% of patients were bridged to NIV, and 28.9% of patients got intubated. **Conclusion:** The aim of presenting our experience is to generate interest regarding innovations in the face of crisis which may not be perfect but are practical for the situation. We do not recommend the use of Bain's circuit to provide NIV support under normal circumstances. Further studies are needed to support the use of Bain's circuit with modifications as a CPAP/NIV delivering device in selected patients.

Keywords: Bain's circuit, COVID pneumonia, innovation, noninvasive respiratory support

Introduction

COVID-19 was declared a pandemic on March 11, 2020 by the World Health Organization. During April and May 2021 health facilities in India got overwhelmed because of a surge in the number of sick patients. Hypoxia was the main reason for admission to intensive care units (ICU) and a leading cause of mortality among patients with severe COVID pneumonia. Patients who did not respond to high-flow oxygen by nonrebreathing mask (NRBM) needed additional support to deliver oxygen with pressure. Since invasive mechanical ventilation in COVID has been associated with very high morbidity and mortality (around 40%), the focus of treatment was on noninvasive methods of respiratory support such as high-flow nasal oxygen (HFNO), continuous positive airway pressure (CPAP), and noninvasive ventilation (NIV) with its inherited risks.[1] A recent meta-analysis performed on 3800 patients showed that helmet or face mask NIV and HFNO were associated with a lower risk of endotracheal intubation as compared to standard oxygen therapy.[2] However, equipment such as standalone noninvasive ventilators, conventional ventilators, or high-flow nasal cannula (HFNC) are all quite expensive and it was difficult to procure them in a resource-limited setting, especially in a short duration of time of COVID 2nd wave. Moreover, during this wave, these pieces of equipment became critically deficient even in the most equipped tertiary level health-care facilities, due to a massive surge in demand. The ability of any health-care facility to manage patients with hypoxia became critically

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dependent on their ability to provide oxygen and respiratory support.[3]

Many centers tried modifications of existing types of equipment or devised novel use of existing technology to deliver respiratory support.[4,5] One such innovation was to use the Bain's circuit to deliver CPAP along with 100% oxygen in patients with COVID-19.[6,7] In this study, we present our experience with using Bain's circuit as a CPAP-delivering device in patients with COVID-19.

Materials and Methods

Study design and setting

It is a retrospective observational study conducted at two high-volume, government-designated, tertiary-level COVID centers of Northern India, during May and June 2021. This study was conducted at a time when the 2nd wave of COVID in India was at its peak, many hypoxic patients were coming to the hospital, and the demand for NIV delivering equipment such as ventilators with NIV mode, bi-level positive airway pressure (BIPAP) machines, and HFNO machines, outstripped the supply. Bain's circuit was used as an emergency measure to provide CPAP as a bridge therapy till ventilators (noninvasive mode), BIPAP machines, or HFNC could be arranged or till the patient's diseased lungs become better and he/she gets weaned off to oxygen by NRBM. The authors would like to emphasize that this is just an observational study under exceptional circumstances where a large number of patients were dying within a few hours of getting admission or even while waiting for admission. Under normal circumstances, we do not recommend using Bain's circuit to provide continuous airway pressure as there are many limitations associated with using Bains circuit for this purpose and it has not been evaluated for this use.

Ethical clearance was taken from the institutional ethical committee (IEC number June 1, 2021).

Medical records of patients admitted to COVID ICU during April and May 2021 were evaluated and all patients fulfilling the criteria were selected. Inclusion criteria for this observational study included all COVID-19 patients diagnosed by reverse transcriptase-polymerase chain reaction test or by computerized tomography scan, belonging to either sex, in the age group of 16–85 years, presenting to hospital emergency with respiratory distress, on oxygen support by NRBM and requiring one of the following:

1. Noninvasive respiratory support and nonavailability of NIV Ventilator/BIPAP machine/HFNC machine
2. Low oxygen saturation (spO2) of < 85% on NRBM with an oxygen flow rate of 15 L, either on presentation or on deterioration during the stay in hospital
3. Patients tachypneic with the respiratory rate (RR) >35 irrespective of spO2 value.

Patients with nonmaintainable airway, depressed sensorium (no response to pain/no response), and patients who did not consent for this intervention were excluded.

Equipment used included; standard Bain's circuit in working condition (prechecked) (Make Romson/Intersurgical) along with nonventilated NIV mask (Make Resmesd or Fischer Paykel) with straps, and heated moisture exchanger (HME) filter (Make Romson/intersurgical).

Technique

After taking informed consent from all patients included in the study, a nonventilated NIV mask was used as the interface between Bain's circuit and the patient for making a tight seal. The mask was placed in such a way that it covered the nose and mouth providing an airtight seal and is secured by straps around the head [Figure 1]. The machine end of the Bain's circuit was attached to the oxygen supply, as shown in the Figure 1 and the patient end was attached to the NIV mask. A HME filter was placed between the patient end of the Bain's circuit and the mask for humidification and to reduce aerosol transmission [Figure 2]. The oxygen supply was kept at 2–2.5 times the minute volume of the patient for effective carbon dioxide (CO2) removal and to prevent rebreathing as recommended in the literature and original description of Bain's circuit for spontaneous breathing.[8] The reservoir bag was kept inflated at all times. The expiratory valve was kept partially open such that the reservoir bag is neither overinflated (for the leak of expiratory gases) nor kept collapsed (ineffective ventilation) and continuous flow of oxygen was insured at all times. The patient's breathing was assessed by inflation and deflation of the reservoir bag. A nasogastric tube (Ryle's tube) was inserted to decompress the stomach and for feeding. This insured minimum disruption of oxygen therapy and better patient compliance.

All patients on respiratory support by Bain's Circuit were continuously monitored for vital signs-RR, heart rate (HR), systolic blood pressure (SBP), and spO2. The use of accessory muscles and sensorium was also observed and documented. These parameters were recorded on admission, before putting the patient on Bain's circuit, at 30 min, and 6 h after the initiation of Bain's circuit. Partial pressure of Co2 on arterial blood gas (PaCo2) was also recorded before application of

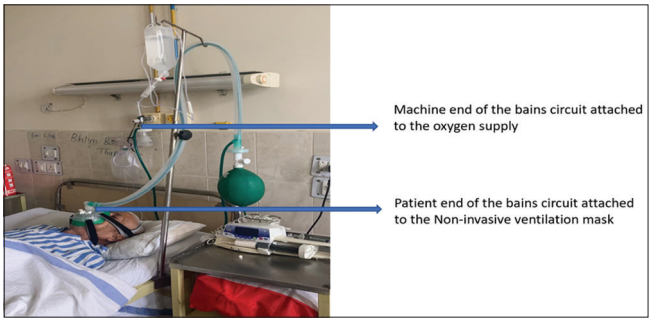

Figure 1: Figure showing the application of Bain's circuit as respiratory support. The NIV mask is placed on the face of the patient in a way that it covers the mouth and the nose, providing an airtight seal, and is secured by straps around the head. The machine end of the Bain's circuit is attached to the oxygen supply as shown in the figure and the patient end was attached to the NIV Mask. NIV: Noninvasive ventilation

Bain's circuit and 6 h after initiation of Bain's circuit whenever available. The total duration for which the patient was on Bain's circuit was also noted. The intervention was considered successful if an improvement in these parameters (increase in SpO_2, reduction in HR, RR, and normalization of blood pressure) was noticed. Improvement in sensorium and decrease in the work of breathing after initiation on Bain's circuit was also observed. However, it was considered a failure if there was intolerance of mask by the patient, worsening in work of breathing/apnea/shallow breathing, worsening of sensorium, and vital parameters was recorded.

Statistical analysis

Data were evaluated and the categorical variables were described in frequency and percentage and the continuous variables were described in mean ± standard deviation (SD). Descriptive statistics were used to evaluate the baseline characteristics.

For SPO2, HR, RR and SBP, repeated-measures ANOVA with a Greenhouse-Geisser correction was used with *post hoc* tests using the Bonferroni correction. For pCO2, a paired-sample *t*-test was used. For use of accessory muscles and altered sensorium, Chi-square test was used; $P < 0.05$ was considered statistically significant.

Results

Our study included 45 patients suffering from COVID pneumonia who fulfilled the inclusion criteria and received respiratory support via Bain's circuit. These patients were admitted during May and June to two tertiary care hospitals in India. The baseline characteristics of these patients are tabulated in Table 1. Baseline Spo2 before applying Bain's circuit in patients with COVID pneumonia was 76.42 ± 7.77 (mean ± SD). Before applying Bain's circuit, all patients had tachycardia 106.1 ± 15.8/min (mean ± SD), tachypnea 33.9 ± 5.8/min (mean ± SD) and were hypertensive 137.7 ± 14 mmHg (mean ± SD). The value of paCo2 was available in only 40 patients and ranged from 15 to 94 mmHg (40.49 ± 18.38 mean ± SD).

All patients included in the study tolerated Bain's circuit for 6 h. There was a significant reduction in the work of breathing after the application of Bain's circuit. The majority of patients showed the use of accessory muscles before Bain's circuit (82.2%), but after 6 h of application of Bain's circuit, there was a significant reduction in the work of breathing and only 20% showed the use of accessory muscles ($P = 0.0001$). Sensorium also showed a significant improvement after the application of Bain's circuit ($P = 0.0001$). Before applying Bain's circuit, only 22.2% of patients were calm and 77.8% of patients were drowsy or irritable. However, after applying for Bain's circuit as respiratory support, 84.4% of patients became calm, and rest 15.6% of patients remained drowsy or irritable. In the first 6 h of the commencement of Bain's circuit as respiratory support, there were significant improvements in HR 106.13 ± 15.84–91.53 ± 10.40 (mean ± SD), RR reduced from 33.87 ± 5.83 to 26.29 ± 3.79 (mean ± SD), and SPo2 increased from 76.42 ± 7.77 to 91.33 ± 3.83 ($P < 0.0001$). The trend of the study parameters is shown in Table 2 and Figure 3.

Table 2 shows the trend in the vitals of the patients after applying Bain's circuit as respiratory support. Systolic BP showed an initial reduction at 30 min of application of Bain's circuit (from mean ± SD of 137.7 ± 14.0 mmHg to 129.5 ± 15.9 mmHg) and then showed a rising trend at 6 h (mean ± SD of 130.4 ± 14.2 mmHg), but overall there was a significant reduction in hypertension ($P < 0.0001$). Although pCo2 rose from mean ± SD of 40.5 ± 18.4 mm Hg to a mean ± SD of 44.3 ± 19.5 mm Hg, it is still in the range of permissive hypercapnia ($P = 0.026$). In our cohort, the median duration of Bain's circuit usage was 42 h ranging from 4 to 266 h. The outcome of patients who were given respiratory support via Bain's circuit is described in Table 3. About 40% of patients who received Bain's circuit were weaned off to oxygen by NRBM, 31.1% of patients were bridged to NIV and 28.9% of patients got intubated.

Table 1: Baseline characteristics of the cohort ($n = 45$)

	Frequency (%)
Age (mean±SD)	57.7±16.1
Sex	
Female	16 (35.6)
Male	29 (64.4)
Severity on admission	
Mild	1 (2.2)
Moderate	16 (35.6)
Severe	28 (62.2)
Comorbidities	
Hypertension	15 (33.3)
Diabetes mellitus	13 (28.9)
Obesity	6 (13.3)
Chronic kidney disease	2 (4.4)
B cell lymphoma	1 (2.2)
Coronary artery disease	1 (2.2)
Liver cirrhosis	1 (2.2)
No comorbidities	6 (13.3)

SD: Standard deviation

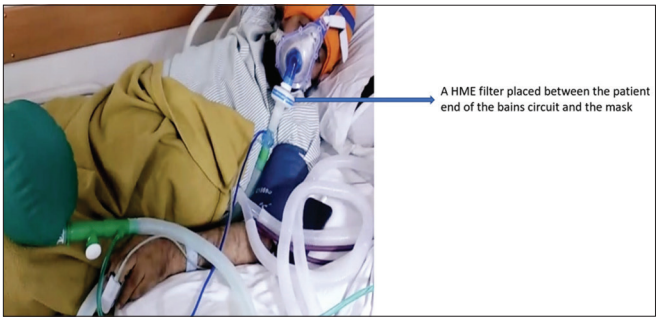

Figure 2: A HME filter is placed between the patient end of the Bain's circuit and the NIV mask for humidification purposes and to reduce aerosol transmission. HME: Heated Moisture Exchanger, NIV: Noninvasive ventilation

Table 2: Parameters before and after Bain's circuit initiation

	Mean±SD/frequency (%)			*P*
	Before Bain's circuit initiation	After 30 min of Bain's circuit initiation	After 6 h of Bain's circuit initiation	
SBP	137.73±14.01	129.47±15.89	130.36±14.18	0.0001
RR	33.87±5.83	28.89±3.93	26.29±3.79	0.0001
HR	106.13±15.84	95.47±11.59	91.53±10.40	0.0001
SpO_2	76.42±7.77	88.67±5.33	91.33±3.83	0.0001
pCO2	40.49±18.38	-	44.33±19.45	0.026
Accessory muscle use				
Yes	37 (82.2)	16 (35.6)	16 (20)	0.0001
No	8 (17.8)	29 (64.4)	29 (80)	
Sensorium				
Calm	10 (22.2)	38 (84.4)	38 (84.4)	0.0001
Irritable	29 (64.4)	5 (11.1)	4 (8.9)	
Drowsy	6 (13.3)	2 (4.4)	3 (6.7)	

SD: Standard deviation, SBP: Systolic blood pressure, RR: Respiratory rate, HR: Heart rate, SpO2: Oxygen saturation, pCO2: Partial pressure of carbon dioxide

Table 3: Outcome for patients enrolled in this study

Outcome	Frequency (%)
Intubation	13 (28.9)
NIV	14 (31.1)
NRBM	18 (40.0)
Total	45 (100.0)

NIV: Noninvasive ventilation, NRBM: Nonre-breathing mask

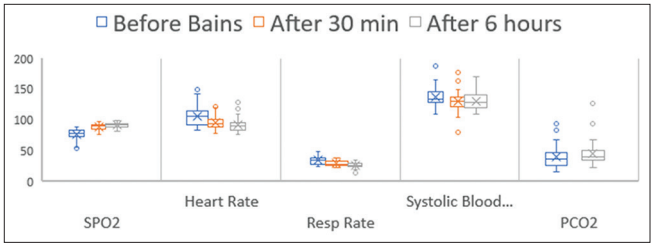

Figure 3: Trend of parameters on Bain's Circuit. For SPO2, Heart Rate, Respiratory rate and Systolic Blood Pressure, repeated-measures ANOVA with a Greenhouse-Geisser correction was used with *post hoc* tests using the Bonferroni correction. For PCO2, a paired-sample *t*-test was used. SPO2: Oxygen saturation

Discussion

During the COVID pandemic, acute hypoxemic respiratory failure was the main cause of admission to ICUs and we realized that high-flow oxygen was not sufficient for many patients, and they required some pressure to assist their spontaneous breathing and relieve their respiratory distress. Since invasive ventilation was associated with very high mortality and morbidity in COVID patients, emphasis was to initiate noninvasive ventilation support, such as CPAP, NIV via ventilator or BIPAP machines, or HFNC in patients with hypoxemia and respiratory distress. Moreover, NIV also acts as an appropriate bridging adjunct therapy in the early part of the disease process and may prevent the need for invasive ventilation. In an international survey done on 1132 patients across 85 nations, the initial choice of oxygen therapy chosen by intensivists in severe hypoxemia was HFNO (47%), CPAP or NIV (26%), and tracheal intubation (7%), and rest 20% receiving conventional oxygen therapy.[9] Various measures were tried to overcome the shortage of ventilators, such as using a "splitter technique" which allows the use of one ventilator for 2 or more patients[10] and developing low-cost mechanical ventilators. One such prototype was based on modifications on the self-inflating bag with additions to control volume, breath rate, and positive end-expiratory pressure (PEEP).[11] During the swine flu epidemic in Pune, an innovative low-cost bubble CPAP was found to be effective in relieving respiratory distress.[12] Our use of Bain's circuit to provide continuous positive expiratory pressure was also one such innovation borne out of necessity in face of acute shortage of equipment providing noninvasive ventilation.

All anesthesia breathing circuits consist of tubing, an adjustable pressure limiting valve (APLV), and a reservoir bag. Prof William Mapleson classified these circuits into 6 categories (A to F) based on the location of the gas inlet, reservoir, and APLV.[13] Drs. Bain and Spoerel's modification of the Mapleson D circuit, popularly known as "Bain's circuit" is the most commonly used circuit.[14] It has a coaxial system with an inner small-bore tube that delivers fresh oxygen or anesthesia gas, while outside, there is a wide-bore corrugated tube for exhaled gas. Fresh gas flow is near the patient inlet, thus reducing dead space, whereas APLV is located at the distal end with a reservoir bag. The valve can be adjusted to provide some resistance to expiration and thus provides CPAP. This innovative way of providing CPAP while delivering 100% oxygen has not been studied extensively in the past, but there is some literature to support its use as a CPAP device in resource-limited settings and during transportation.[7,15] Sanabria *et al.* have also reported that Bain's circuit could be successfully used to provide noninvasive ventilatory support in children with acute respiratory failure, although they used the nasopharyngeal tube as an interface.[16]

Our study demonstrated that Bain's circuit is an effective and safe way to deliver NIV/CPAP support with 100% oxygen in patients with COVID-19 for at least 6 h, if other equipment for providing respiratory support is not available. All patients included in our study showed significant improvements in vitals HR, RR, Spo2 after the application of Bain's circuit. Another study done on children with respiratory failure demonstrated similar findings and showed significant improvement in Pao2/Fio2 and reductions in HR and RR after the application of Mapelson D circuit as CPAP support.[17] In the present study, all 45 patients tolerated Bain's circuit well. There was also a significant improvement in patient comfort, sensorium, and work of breathing after initiation of Bain's circuit, and this trend was noticed as soon as 30 min of application of Bain's circuit and it continued for the entire duration of the study (6 h). Although for this study, 6 h was arbitrarily decided as the duration for observation for the ease of the study in the pandemic, many patients continued to remain on Bain's circuit because of the nonavailability of ventilators. The longest duration on Bain's circuit observed in our study was 266 h. Time limit of 6 h was selected to emphasize that we did not consider Bain's circuit a definitive respiratory support modality and every effort was made to arrange NIV equipment whenever any patient was placed on Bain's circuit. Only adverse effect seen was an increase in CO2 levels, but it was in the range of permissible hypercapnia and no patient had CO2 high enough to cause narcosis or any other harmful effects. In terms of outcome, 40% of the patients were weaned off to oxygen by NRBM, about one-third of patients were bridged to NIV, and the rest 28.9% required intubation. Several studies done on the effectiveness of NIV in COVID-19 acute respiratory distress syndrome (ARDS) have shown successful weaning and avoidance of intubation only in around 30%–50% of patients, and the outcome also depends upon the severity of the disease, comorbidities, and experience of medical personnel and several other factors.[18] Even in patients with non-COVID moderate-to-severe ARDS, the success rate of NIV observed is close to 53%–57%.[19] Therefore, we observed that our success rates with Bain's circuit were quite comparable to NIV success rate in COVID and non-COVID ARDS and our experience shows that during the nonavailability of conventional CPAP delivery devices, Bain's circuit led to significant improvement in oxygenation, patient comfort, and sensorium, which allowed us to buy time to arrange NIV. It also gave satisfaction and relief to patients with hypoxia and their distressed family members in circumstances of nonavailability of NIV equipment. If Bain's circuit was not available, these patients may not have survived till the time alternative respiratory support methods could be arranged. We found that Bain's circuit was easily available, affordable, and very easy to use. There was no special training required to handle the equipment and it was easy to maintain while in use. We also observed that some patients remained so comfortable and had better tolerance on this equipment that later they preferred it over the conventional NIV support.

There are definite limitations with this equipment like the risk of rebreathing and Co2 retention. We could not measure pco2 values in all our patients included in the study. We were not able to measure what exact PEEP or pressures were delivered nor could we titrate PEEP as there were no marks on the valve to show how tight or loose it was. There was also the risk that the valve may become loose inadvertently or get mishandled and can cause loss of PEEP. The flow was also not adjustable as the flow meter shows up to 15 L/min only. The observation period of 6 h was arbitrary, for the ease of the study during the overloaded pandemic period. We also could not identify any subsets of patients who are likely to benefit more or patients who may not benefit from this intervention as all 45 patients behaved uniformly in this study. The addition of a few modifications such as measurement and titration of PEEP along with the use of a blender to deliver humidified oxygen air mixture with regulated FIO2 can make this a cost-effective equipment to deliver NIV, which is very easy to use during emergencies during resource crunch setting. There was not much literature available to use Bain's circuit for delivering CPAP, but at that time, there were not many options available, even transferring patients out was not an option as all the hospitals were overloaded and exhausted.

Conclusion

Our study revealed that Bain's circuit could provide CPAP with 100% oxygen in an indigenous way in selected patients with COVID-19 requiring NIV in resource-limited settings, whenever NIV machines are not available. This is an observational study and should not be considered as recommendation of using Bain's circuit to provide NIV support under normal circumstances. The aim of presenting our experience is to generate interest regarding innovations in the face of crisis which may not be perfect but are practical for the situation. Further studies are needed to support the use of Bain's circuit with modifications as a CPAP/NIV delivering device in selected patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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