Bain H: Innovative Modification of Bain Circuit for the Resuscitation and Transportation of Patients With Coronavirus Disease 2019

Anshul Jain, MD,* Rachna Chaurasia, MD,† Narendra Singh Sengar, DM,‡ and Akash Deep, MD*

Bain H circuit is an innovatively modified breathing circuit designed for the transportation and resuscitation of patients with coronavirus disease (COVID-19). For this circuit, the Heidbrink valve was replaced with a 15F inlet and 15M/22F outlet adjustable pressure-limiting (APL) valve, and a high-efficiency particulate air filter was placed over the APL outlet valve. The circuit is designed to filter the novel coronavirus without any increase in dead space or resistance. All benefits of the conventional Bain circuit were retained. Besides its use in dedicated COVID-19 areas, this circuit can be used in other emergency units of the hospital. (A&A Practice. 2021;15:e01530.)

GLOSSARY

APL = adjustable pressure-limiting; **COVID-19** = coronavirus disease 2019; **HEPA** = high-efficiency particulate air; **HME** = heat and moisture exchanger; **ICU** = XXX; **RT-PCR** = reverse transcription polymerase chain reaction; **SARS-CoV-2** = severe acute respiratory syndrome coronavirus 2; **WHO** = World Health Organization

Health care systems worldwide have been strained by coronavirus disease 2019 (COVID-19), the deadliest pandemic of the current century. The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that causes COVID-19 is highly contagious and is mainly transmitted through respiratory droplets. COVID-19 infections usually follow the inhalation of respiratory droplets exhaled from an infected person, and these respiratory droplets can remain in the air for a prolonged period.[1]

Health care workers are at significant risk for airborne infections because of their proximity to patients. Therefore, the World Health Organization (WHO) has recommended that airborne and contact precautions be observed during aerosol-generating procedures.[2] Health care workers in critical areas and in emergency care are at the highest risk for exposure.[2] Many international bodies have recommended to restrict resuscitation and intubation in triage areas, as resuscitation generates aerosols and is likely to contaminate the vicinity. This restriction is directly related to a lack of suitable resuscitation equipment that can effectively prevent the release of infective aerosols into the atmosphere.

Before the COVID-19 pandemic, the conventional Bain circuit (coaxial modification of the Mapleson D system) was the most common breathing circuit used for resuscitation, transportation, preoxygenation, and administration of anesthesia. However, Bain circuit has been avoided during the COVID-19 crisis as the exhaled gases are vented through the Heidbrink adjustable pressure-limiting (APL) valve directly to the surrounding atmosphere and may infect health care workers in the vicinity.[3–5] To overcome this limitation, the authors have modified the conventional Bain circuit into a fully functional and secure device that is designed to filter the expired air before it is released into the atmosphere. The authors have termed this the Bain H circuit, where the "H" stands for high-efficiency particulate air (HEPA) filter.

DESCRIPTION

For the current modification, the authors added 3 additional items to the conventional Bain circuit:

- T-piece connector with 22M and 22F horizontal ends and a 15M vertical end (Figure 1A).
- APL valve with 15F inlet and 22F/15M outlet and a pressure range of 0 to 60 cm H_2O (supplied by Romson India Pvt Limited) (Figure 1A–D).
- 22F/15M–22M/15F adult HEPA hydrophobic bacterial/viral filter with 1.7-cm H_2O resistance at 30 L/min and a viral filtration efficiency of 99.999% (Flexicare Medical Limited Cynon Valley Business Park) (Figure 1E).

The authors replaced the existing inline Heidbrink valve of the conventional Bain circuit with a 22M to 22F T-piece and connected the 15F APL valve to the 15M vertical limb of the T-piece. The HEPA filter was placed at the APL outlet valve. The 15F HEPA filter connection fits snugly over

From the *Department of Anaesthesiology, †Department of Radiodiagnosis, and ‡Department of Nephrology, Maharani Laxmi Bai Medical College, Jhansi, India.

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Address correspondence to Anshul Jain, MD, Department of Anaesthesiology and Critical Care Medicine, Maharani Laxmi Bai Medical College, AH-2/9 Veerangna Nagar, Jhansi 284128, India. Address e-mail to dranshuljain81@gmail.com.

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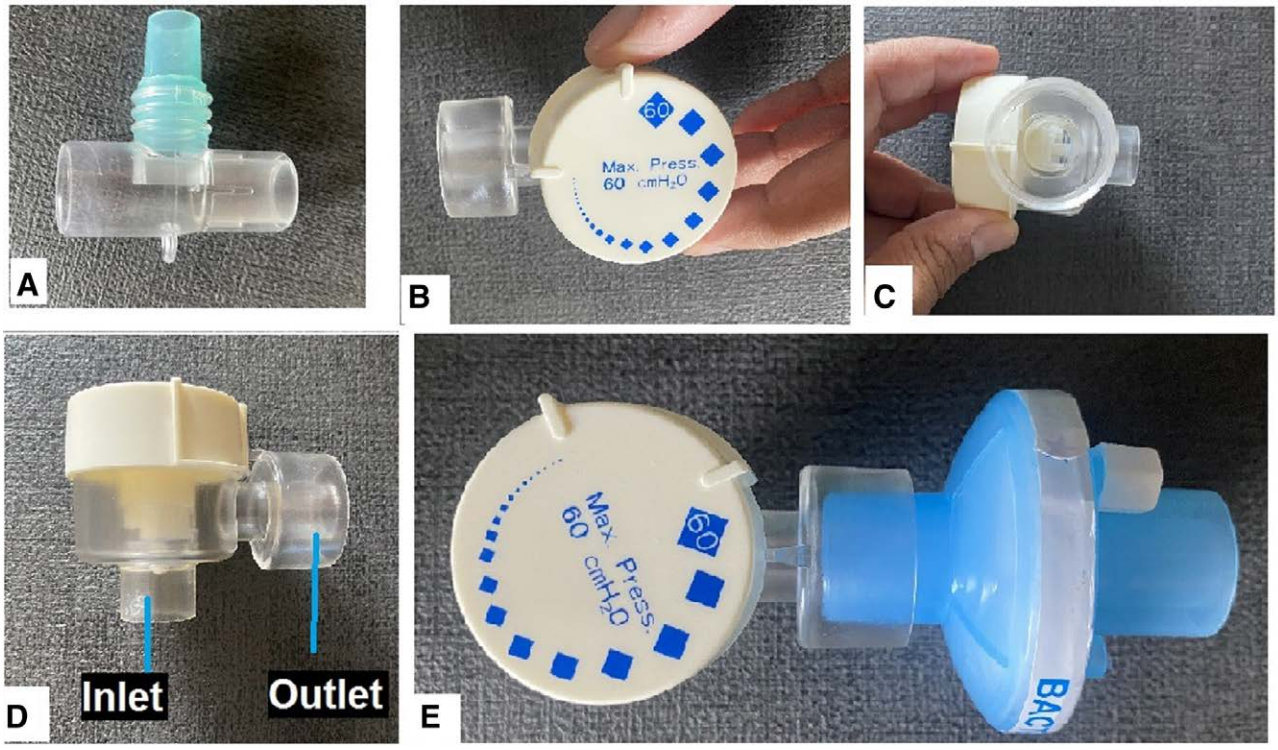

Figure 1. APL valve and HEPA filter assembly of Bain H circuit. A, 22M/22F-15M T-piece. B, APL valve from top. C and D, 15M-22F outlet of APL valve. E, HEPA filter applied over the outlet of APL valve. APL indicates adjustable pressure-limiting; HEPA, high-efficiency particulate air.

the 15M outlet of the APL valve. No other changes were made to the reservoir bag, corrugated tube, inner 7-mm tube, or patient connector (Figure 2). The flow resistance of circuit was found to be 2.8 cm H_2O at a flow rate of 30 L/min. The working mechanics remained the same, and the 7-mm internal diameter tube allowed for fresh gas and oxygen to be connected to a flowmeter or anesthesia workstation. For spontaneous breathing, the recommended flow rate remained 2 times the minute ventilation, and the APL valve is recommended to be fully open. On inspiration, the patients breathe in the fresh gas coming directly through the fresh gas outlet and the gas stored in the annular space between the inner and outer tubes. On expiration, the exhaled gases enter the annular space of the circuit (as with the conventional Bain circuit) and pass through the fully open APL valve to the HEPA filter and then out to the atmosphere (Figure 2A). Under controlled ventilation, the mechanics are the same as those of the conventional Bain circuit, except the exhaled air goes to the atmosphere only after filtration, and the APL valve can be adjusted to the desired level. The minimum recommended fresh gas flow during controlled ventilation should be twice of minute ventilation. For the current pandemic, disposal of the whole circuit as biomedical waste is warranted to prevent cross contamination between patients.

Several notable advantages of the current circuit are listed as follows:

- Effective filtration of bacteria and viruses, including SARS-CoV-2
- Lightweight design and retained benefit of heat and moisture exchange
- No increase in dead space
- Can be used both in COVID-19 and non-COVID-19 areas of the hospital
- Pressure indicators on APL valves allow for emergency physicians or anesthesiologists to set the appropriate pressure
- Can be used for transporting and resuscitating patients with COVID-19
- Overall, Bain H circuit has been designed to reduce the risk of infection transmission related to the breathing circuit

DISCUSSION

Since the beginning of the COVID-19 pandemic, the WHO has paid equal attention to patient care and infection prevention among health care workers. Owing to the highly variable symptomatology associated with COVID-19 and limitations of reverse transcription polymerase chain reaction (RT-PCR) assays, it has been difficult to rule out active SARS-CoV-2 infections in patients admitted for surgical procedures or other nonrespiratory reasons. This issue becomes more significant for patients with COVID-19 who present to the emergency unit, particularly for conditions in which a delay in treatment can be deleterious. Bain circuit, the coaxial modification of a Mapleson D system, was introduced by Bain and Spoerel[6] in 1972, and it has become the universal circuit used for resuscitation, administration of anesthesia, and transportation of sick patients.[7] Mapleson D is the most efficient Mapleson circuit for patients on positive pressure ventilation and is the second most efficient circuit for those breathing spontaneously. Mapleson A is most efficient for patients breathing spontaneously but

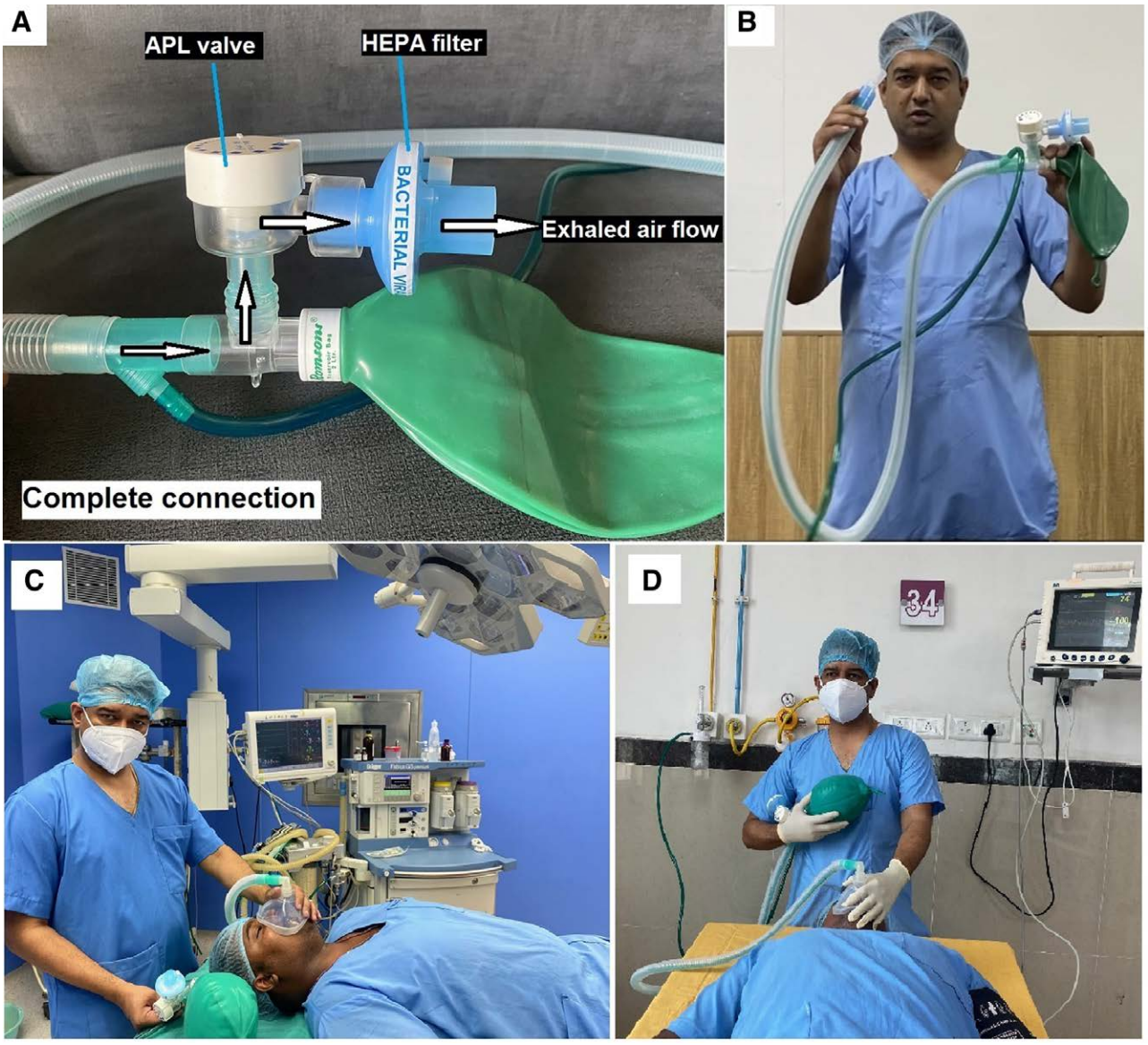

Figure 2. Assembly and demonstration of Bain H. A, Entire assembly showing the direction of the exhaled air flow. B, Complete Bain H circuit. C, Bain H connected to anesthesia workstation as would be used in the operating room. D, Bain H connected to a flowmeter as would be used for resuscitation in the ICU. Demonstration was performed by author (A.J.), and coauthor (A.D.) acted as subject. APL indicates adjustable pressure-limiting; HEPA, high-efficiency particulate air; ICU, intensive care unit.

least efficient for patients on positive-pressure ventilation; it is, therefore, not commonly used in the perioperative setting or for resuscitation. Bain circuits are commonly used because they ensure a minimal work of breathing and are reliable and inexpensive. The main limitation of a Bain circuit, which has been evident during the current pandemic, is the direct release of exhaled gases through the Heidbrink APL valve into the atmosphere. Patients infected with SARS-CoV-2 are likely to exhale the virus during coughing and sneezing. Positive-pressure ventilation in intubated patients further increases the risk of exhaling the virus.[8] Published literature has shown that HEPA filters can be used to effectively filter the SARS-CoV-2 virus, and scientific societies have recommended that HEPA filters be used for ventilators and tracheostomy tubes.[9,10] With the current modifications, the authors effectively placed an HEPA filter (or a heat and moisture exchanger [HME] filter of the same connection diameter) at the expiratory outlet of the breathing circuit. Chen et al[11] also recommended the installation of an artificial nose (breathing circuit filter) to filter out exhaled gases. Though the HEPA filter can be placed between the endotracheal tube and circuit, it may be deleterious if the filter gets saturated with water vapor or with another fluid. This will significantly increase the resistance of the circuit. Further, adding any device or filter downstream to the fresh gas flow will increase the dead space. Using the filter near the pop-off valve will limit contamination with fluid and has no effect on dead space.

This modification is not the first that has been attempted, as previous clinicians have published their make-shift designs to overcome this limitation of the Bain circuit. Kumar et al[12] assembled a modified Bain circuit using a

glove, suction tube, and single-chamber underwater seal system containing a 1% sodium hypochlorite solution in which the exhaled gases were vented through a Heidbrink APL valve, passed through the glove's pouch, and entered into the underwater seal system containing the sodium hypochlorite solution through a suction tube. However, with this design, adjusting the APL valve was difficult, and the glove pouch was prone to leakage. In a more scientifically feasible modification, another group of researchers created what they termed a coaxial modification of the Mapleson B system by repositioning the Heidbrink APL valve at the end of the endotracheal tube and placing an HME filter between the endotracheal tube and the Heidbrink APL. Notably, the Mapleson B system is ranked after both the Mapleson D and C systems in terms of efficiency. Additionally, placing the HEPA filter downstream of the fresh gas flow also increases dead space.[13] Finally, Tyagi et al[14] also modified the Bain circuit by applying 2 HME filters, one at the endotracheal tube end and another just proximal to the Heidbrink valve. However, they reported that rebreathing, increased circuit resistance, and higher gas flow requirements were possible limitations of the system.

The Bain H circuit allows for exhaled gases to pass through an HEPA filter without requiring any functional modification to the circuit. While the current modification has all the functional limitations of a Bain circuit, it is free of any new limitations except for a minimal increase in cost. Caution must be exercised while using a Bain H circuit with a facemask, as this device does not prevent the leak of exhaled aerosols from around an imperfect seal between the patient's face and the mask.

CONCLUSIONS

With the current pandemic crisis, Bain H circuit is an effective substitute for the conventional Bain circuit.

DISCLOSURES

Name: Anshul Jain, MD.
Contribution: This author helped provide the intellectual content, design the equipment, validate the equipment, write the manuscript, see the original study data, and approve the final manuscript, and is responsible for archiving the study files.
Name: Rachna Chaurasia, MD.
Contribution: This author helped provide the intellectual content, search the literature, write the manuscript, see the original study data, and approve the final manuscript, and is responsible for archiving the study files.
Name: Narendra Singh Sengar, DM.
Contribution: This author helped provide the drawings of the figures and literature for the manuscript, see the original study data, and approve the final manuscript, and is responsible for archiving the study files.
Name: Akash Deep, MD.
Contribution: This author helped provide the drawings of the figures and literature for the manuscript, see the original study data, and approve the final manuscript, and is responsible for archiving the study files.
This manuscript was handled by: BobbieJean Sweitzer, MD, FACP.

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