Automating Bag-Valve-Mask Attachment

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Abstract

The bag-valve-mask (BVM) is the most commonly used manual ventilation device in the prehospital and emergency setting for patients who have impaired ventilation or cardiac arrest[1]. However, there is widespread heterogeneity in the quality and sufficiency of ventilation delivered using this technique[2]. Adequate tidal volume (TV) delivery is achieved by watching for chest rise, and safe proximal pressure delivery is modulated by the subjective timing of the bag squeezing activity[3] ; Both can be difficult to monitor in a moving ambulance or while giving chest compressions during cardiopulmonary resuscitation. Additionally, this is compounded by potential fatigue of the technician. The Automating BVM Attachment device converts the manual ventilation device into a volume-controlled, pressure monitoring automated ventilation system that delivers more precise and accurate ventilations, while alleviating technician fatigue and enabling multi-tasking. The device delivers TV, breathing rate, and inspiratory-to-expiratory ratio according to technician input. Air delivery is modulated by a compression system consisting of a motor driven band that shortens and extends around the bag. Audio and visual safety alarms alert the technician if proximal pressures below acceptable post-expiratory pressure (PEEP) or above acceptable post-expiratory pressure (PIP). Additionally, the device is portable and sized for ease of travel in an ambulance. As a disinfectable attachment, it is compatible with existing BVMs and re-usable reducing cost to the user.

Introduction

When patients have difficulty or stop breathing artificial ventilations are necessary. The BVM is the most commonly means of providing these ventilations. Even though it is one of the most commonly used tools in the prehospital environment, providing consistently successful and accurate ventilations, and assessing the quality of the ventilations is difficult due to:

- Watching for chest rise, the conventional procedure for assessing ventilation, is difficult to see in a moving ambulance and may not be feasible while doing chest compressions
- Fatigue by first responders can cause reduction in ventilation quality over time
- Timing and volume of air delivered is subjective to the first responder

Therefore the Automating BVM Attachment improves current BVM capabilities by automating manual ventilation through volume control and pressure feedback according to user inputted ventilation parameters while maintaining the portability of the current BVM.

Figure 1: BVM Performance during CPR.
(Source: EMSWorld)

Design Inputs

- Must be able to **deliver a tidal volume** of air.
- Must be able to **detect a proximal pressure** of air being delivered by the BVM.
- Must **cyclically** deliver air volume within the tidal volume range recommended by the AHA for BVM use
- Air must be delivered according to **user-set values** of parameters
- Must give **visual and audio feedback** to the user when proximal pressure is outside the range of safe pressure.
- Device's battery power components must comply with **electrical standards**.
- Device must **fit the current BVM**.
- Device must allow the attachment of the face mask, intake reservoir valve, and oxygen enrichment ports.
- Device must **maintain the portability** of the BVM.
- Automated bag compression device must **easily attach** to the BVM.
- Device must be **rechargeable**; a single charge must last more than the duration of a call.
- The device must allow the user to provide a **proper face seal** more easily than without the device.

Design Solution

Compression Mechanism

Motor winds a strap around a circumferential spool to push the plate and compress the BVM bag, delivering a ventilation

- NEMA 23 Stepper Motor with Stepper Driver with microstep resolution
- Rotary Shaft supported by Sleeve Bearings
- 3D Printed Spool to wind Nylon Compressive Strap
- 1:2 Gear Ratio for appropriate force
- PPE Pusher plate machined for ergonomics

Figure 2: 3D rendered SolidWorks assembly of pusher plate compression mechanism. Red arrow indicates rotation of gear/shaft to wind compressive strap (black/gray) around spool (white).

Pressure Sensing and Control

Pressure sensor is integrated into the already existing PEEP valve BVM port and senses proximal airway pressure.

- Honeywell absolute pressure sensor
- 3D Printed PEEP valve attachment
- Sound and Light alarms activated when pressure reaches outside the safe range (in accordance with safety standards)

Control algorithm to adjust ventilation delivery parameters.

- Raspberry Pi 3 Model B+ for Programming
- User adjustable TV, I/E Ratio, Respiratory Rate
- Suitable for a range of adult body sizes and breathing capabilities

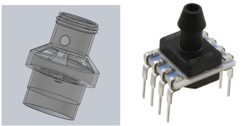

Figure 3 (left) SolidWorks Part of PEEP valve attachment & Figure 4 (right) Honeywell Pressure Sensor. Compatible with existing BVM.

Results & Testing

The is successful in:

- Compressing the BVM bag to deliver tidal volumes
- Measuring proximal airway pressure
- Maintaining distance from all ports
- Being portable in size
- Fitting the average adult BVM
- The ability to be cleaned and reused
- Being deployed in a timely manner
- Attaching the pressure sensor in the existing PEEP valve port

Additional work and testing must be performed to:

- Calibrate the device to be able to adjust to deliver precise volumes and timing with appropriate tolerance
- Validation testing to confirm usability in the field

Figure 4: Physical construction of pusher plate assembly. Pictured on top of Ambu adult BVM.

Figure 5: 3D Printed PEEP Valve pressure sensing attachment. Shown attached to Ambu BVM PEEP valve.

Conclusions

The device has been successfully constructed as a volume controlled, pressure monitoring ventilation attachment by demonstrating the ability to deliver artificial ventilations **a**s well as detect proximal airway pressure. The design is compact, easily attached to current BVM models, allows access to all BVM ports, is able to be sanitized, and is rechargeable offering a portable solution to automate ventilation utilizing existing BVM. Studies to assess the ease of carrying the device and use in a simulated emergency environment are to be completed in future work. Additionally, future work in fine-tuning the programming of the user input control of the ventilations will allow the device to deliver ventilations with various input parameters at a higher accuracy. This device has the potential to benefit emergency medical personnel as well as patients in the prehospital environment.

References

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