An Autonomous, Low-Cost Bag Valve Mask for Emergency Responders

Hannah Clausi [1], Jackie Godinez [1,2], Claire Kenny [1,3], Mimi (Xinyi) Li [1,2], Nate Roblin [1,3]
[1]Biomedical Engineering, [2]Mechanical Engineering, [3]Materials Science and Engineering

Problem

Acute respiratory failure leads to over 1 million people in the US being **admitted to the emergency department per year** [1].

The current method of treatment, **bag valve masks, does not have a way of measuring pressure or flow**, often resulting in lung damage [2].

Background

Acute respiratory failure is a sudden onset of:

- **Difficulty breathing**[6]
- **Shortness of breath** or rapid breathing[6]
- **Unconsciousness**[6]


1)

Responders often use **bag valve masks (BVM)** *(see Figure 2)* to **establish emergency airway support** for the patient [3].

However, there is no feedback of the pressure and flow being delivered, leading to:

2)

- **Lung injury** [4] (barotrauma)
- **Over ventilation** [4] (hyperventilation)
- **Increased morbidity and mortality** [4]

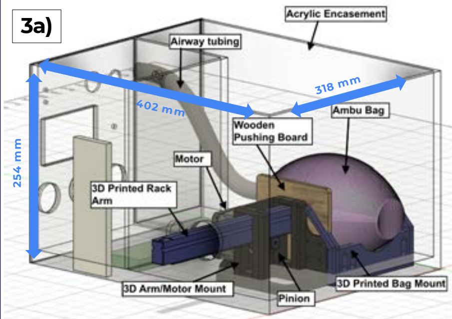
Objectives

Design a **portable, non-invasive, low-cost bag valve mask with autonomous pressure and flow regulation** for patients needing emergency airway support in low resource areas to address BVM complications and in turn **reduce mortality rates amongst patients with acute respiratory failure.**

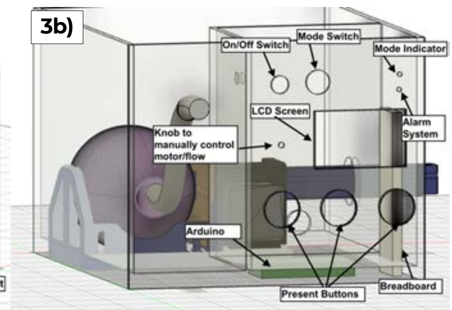
- **Low-cost** (<$350)
- **Portability** (<12"x12"x12" dimensions)
- **Non-invasive**
- **Ease of Use** (set-up time is less than 1.5x standard)
- **Pressure and flow regulation/sensors**

Methods

3a)



3b)



4)

Our design (*See Figure 3a and 3b*) and prototype (*See Figure 4*) was tested using:

- An adult BVM bag
- Pressure bulb and sensor
- BioRadio spirometer (measures flow rates)
- Python code and EXCEL

Results

Our prototype device was evaluated for:

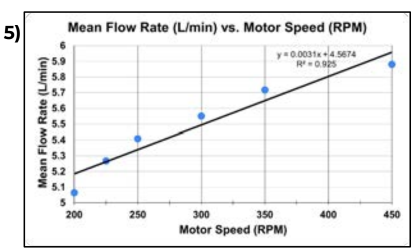
- Whether air is supplied at **sufficient volume** for patient ventilation with **safe pressure/flow vitals** (*See Table 1*)
- Linear regression mapping **motor speed** to **volumetric flow rate** (*See Figure 5*)

Vital	Values Achieved
Tidal Volume (mL)	407.58
Peak Instantaneous Flow Rate (L/s)	≤ 0.82
Mean Volumetric Flow Rate (L/min)	5.48
Inspiratory Pressure (mmHg)	* N/A
Inspiratory Time (s)	≤ 0.79
Time Between Compressions (s)	5.59

Table 1) Testing Values for Ventilation Vitals

* *Inspiratory Pressure values could not be accurately recorded due to electrical interference from wiring*

5)



Conclusions

We were able to satisfy at least 2 of our criterion:

- ✓ **Non-invasive** (Requires no intubation)
- ✓ **Pressure and flow regulation/sensors**

Vital	Criteria Value	Our Device	CMU EMS	Dafilou et al. EMS
Tidal Volume (mL)	350-600	407.58	288.34	807.70
Peak Instantaneous Flow Rate (L/s)	< 2	< 2	1.32	N/A
Mean Volumetric Flow Rate (L/min)	3.5-6.0	5.48	3.95	11.48
Inspiratory Pressure (mmHg)	< 11	N/A	6.69	12.50
Inspiratory Time (s)	1-2	≤ 0.79	0.41	N/A
Time Between Compressions (s)	6	5.59	4.38	4.22

Red: Values are ***higher than*** criteria values

Blue: Values are ***lower than*** criteria values

Table 2) Comparison to EMS Data and Criteria Values

Future Work

time and budget being a major constraint here are some potential areas of improvement for the future:

- **Design an integrated circuit** to reduce electrical interference and improve portability
- **Perform pressure testing** to determine if the supplied inspiratory pressure is sufficiently low to avoid barotrauma
- **Determine optimal materials** for the final product (we were limited in our materials due to our budget)
- **Add a power source** (12+ volts to accommodate both the motor and Arduino)

Acknowledgments

We would like to thank **Dr. Conrad Zapanta, Samuel Moss, Kyle Bannerman, Ryan Bates, Sarah Hargett and Keshav Reddy** for helping and supporting us throughout our design process.

References

1. Stefan, M. S., Shieh, M. S., Pekow, P. S., Rothberg, M. B., Steingrub, J. S., Lagu, T., & Lindenauer, P. K. (2013). Epidemiology and outcomes of acute respiratory failure in the United States, 2001 to 2009: a national survey. Journal of hospital medicine, 8(2), 76–82. https://doi.org/10.1002/jhm.2004
2. Jacob, D. (2020, July 15). What Is Bag Valve Mask Ventilation (BVM) Used For? Retrieved November 09, 2020, from https://www.medicinenet.com/what_is_bag_valve_mask_ventilation_bvm_used_for/article.htm
3. The DOS and don'ts of BAG-VALVE Mask ventilation. (2014, August 8). Retrieved April 02, 2021, from https://www.jems.com/patient-care/dos-and-don-ts-bag-valve-mask-ventilatio/
4. Say, S. D. (2020, July 21). Respiratory failure vs. distress. Retrieved April 02, 2021, from https://blog.sscor.com/respiratory-failure-vs.-distress
5. Dafilou, B. (2020, Apri 27). It's In The Bag: Tidal Volumes in Adult and Pediatric Bag Valve Masks. The western journal of emergency medicine, 21(3), 722-726. https://doi.org/10.5811/westjem.2020.3.45788
6. Respiratory Failure (Acute vs. Chronic): Causes, Symptoms, Diagnosis. (2019, October 29). Retrieved November 13, 2020, from https://www.webmd.com/lung/acute-chronic-respiratory-failure