A Method of Powering a Nebulizer Manually Using Parts Locally Available in Honduras

Roger Dzwonczyk, Matthew Brockman, Daniel George
Nathan Hankins, Marissa McHugh, Mariantonieta Gutierrez Soto
College of Engineering
Engineering Education Innovation Center
The Ohio State University
Columbus, OH USA

***Abstract*—The objective of this project was to design and build a simple, low-cost human-powered nebulizer (HPN) using locally available parts purchased in Honduras, and evaluate its clinical performance. The work was performed by students in an international engineering service-learning program at The Ohio State University. Nebulizers are used to treat people with respiratory diseases, e.g. asthma, which have a high prevalence in Honduras. Our design consists of a bicycle pump, two pump needles, plastic medical tubing, a soccer ball, air filter and a nebulizer/mask, all connected in series. A common motorcycle fuel filter serves as the air filter in the system. Pumping the foot-operated bicycle pump generates air pressure/flow in the system. The soccer ball acts as a low-pass mechanical compliance filter to smooth the time-varying pressure/flow pattern. We established a pumping frequency – 40 strokes/minute – that produced a pressure and volumetric flow rate consistent with a commercial electrically-powered medical nebulizer compressor. In a pilot study in Honduras, we compared our HPN – costing USD17 to construct from locally available parts – to a commercial nebulizer – costing several hundred dollars to purchase – as to how each improved the patients' breathing performance. We measured breathing performance before and after treatment with a standard peak-flow spirometer. Each machine improved the patients' breathing performance ($p \leq 0.001$); we found no difference in breathing improvement between the two machines ($p=0.288$) in this small study. Qualitatively, patients in both groups reported improved breathing performance following treatment. Our HPN is currently being used in clinics in the Choluteca region of Honduras where commercial nebulizers and the electricity needed to power them are scarce or unavailable.**

Keywords— Human powered nebulizer; medical devices; respiratory disease

I. Introduction

A. The Nebulizer and Its Use in Treating Respiratory Diseases

A nebulizer is a medical device used to administer water, often with a medication, in the form of a mist inhaled into the lungs. Nebulizers use either pneumatic or ultrasonic power to aerosolize the liquid solution into small droplets that a patient then inhales. Pneumatic nebulizers can deliver a constant flow of droplets when powered by a gas compressor, or a pulsed flow, as produced by a common portable manually-operated pocket rescue inhaler. Nebulizers are used to treat patients suffering from asthma, cystic fibrosis, chronic obstructive pulmonary disease and other respiratory diseases. [1-3]

The simplest pneumatic nebulizer consists of three parts: 1) a gas pressure/flow generator; 2) the nebulizer itself, i.e. the device that aerosolizes the liquid and (3) either a mouthpiece or face mask for the patient to inhale the mist. These parts are connected in series, often with plastic tubing. Commercial nebulizers also include an air filter and may include a pressure and flow gage.

The nebulizer has two effects. First, the introduction of a vaporized liquid into the lungs liquefies thick mucus to reduce clogging, making removal of excess mucus easier. Second, the use of medications such as albuterol cause the smooth muscle to relax. The combination of liquefying the mucus and relaxing the muscle allows the patient to breathe with less difficulty. In the developing world, nebulizer users often do not have access to albuterol or other similar drugs and instead use water only or in combination with chamomile tea. Regardless, this treatment regimen sooths the airway and liquefies the mucus, thus improving the patient's ability to breathe.

B. Problem Statement

A significant portion of the population in Choluteca, Honduras suffers from asthma and other respiratory ailments. Several factors contribute to the high prevalence of these ailments, including: environmental effects, the desert climate, dryness, wind, dusty air including dust storms, allergenic vegetation, open fire garbage burning, burning of vegetation (sugar cane) for fertilization before planting and cockroach infestations that produce allergenic particles. Indoor open-fire cooking is common in Honduras, as well as in the rest of the developing world, and contributes to the problem. According to World Health Organization, 5% of deaths in Honduras in 2014 were caused by chronic respiratory diseases [4]. Asthma, along with other respiratory diseases, is primarily a childhood disease in Honduras. Twelve percent of deaths in children under five years old are attributed to acute respiratory diseases [5].

C. Breathing Treatment in Honduras

Nebulizers can provide relief and treatment for asthma, but are currently largely unattainable in Choluteca, due to limited availability and the high cost of commercial machines. Nebulizers in Honduras can cost several hundred dollars, whereas most Hondurans earn only a few dollars per day.

Availability of nebulizers is restricted mostly to local clinics and public (and private) hospitals. Proper treatment for respiratory patients, particularly in remote villages, is restricted by transportation issues, limited treatment facilities, treatment cost and the large number of patients seeking treatment.

D. Previous Work on Human Powered Nebulizers

Researchers at North Carolina State University described a homemade nebulizer that uses a sealable bottle, such as a soda or water bottle. The bottle is sealed using a cork, and a hole is drilled through the cork to insert a hand or foot pump needle. A small amount of water is placed in the bottle. The bottle is pressurized, and then the cork is removed. The rapid change in pressure causes the water to vaporize, producing a breathable mist [6]. The system us inexpensive but cumbersome to use on a routine basis.

Lars Olson at Marquette University designed a human powered nebulizer that uses bicycle pedals to operate a hand pump that generates a stream of compressed air to power the actual nebulizer [7,8]. This device is well-engineered, but requires a high manufacturing prowess to produce and is expensive.

A team from Massachusetts Institute of Technology (MIT) led by Anna K. Young described a method of making a homemade nebulizer, using a foot pump, a filter, tubing, and the nebulizer [9]. They conducted extensive studies on droplet size distribution vs. volumetric flow with their device. They used the device with some success in Nicaragua. This device served as the basis for our design.

E. Project Objective

Our objective in this work, was to design and build an HPN, and specifically the pressure/gas flow generator used to power the nebulizer; i.e. the device that aerosolizes the liquid, from parts and supplies readily available in Choluteca, Honduras, and compare our HPN to a commercial electrically-powered medical nebulizer. Additionally, we planned to place our HPN into clinical use in hospitals and clinics in the Choluteca, Honduras metropolitan area and train healthcare workers how to build and use the device.

F. Design Constraints

Our HPN had the following design constraints:

- It must improve breathing performance in respiratory patients;
- It must be affordable;
- It must be made from local readily available parts;
- It must be easily constructible by people in Choluteca;
- It must be durable;
- It be human powered;
- It must be small and portable;

G. Deliverables

We committed to deliver the following to the healthcare centers and the people in the Choluteca, Honduras region:

- At least one working HPN of our design;
- All drawings, parts lists, parts venders and instruction/user manuals needed to replicate and use the HPN;
- Training in the construction and use of the HPN;

II. HPN DESIGN

A. HPN Performance Goals

Table I delineates the performance goals for our HPN.

TABLE I. HPN PERFORMANCE GOALS

Metric	Value	Reference Source
Flow rate	8l/min	Recommended by OSU Wexner Medical Center Clinical Engineering Department
Pressure	6-8psi	Direct measurement of a commercial nebulizer at 8l/min flow rate
Particle size	5-40µm	[2,3,9]

B. Configuration of Our HPN

Fig. 1 shows the components of our HPN. They consist of a foot-operated bicycle pump, a standard No. 5 soccer ball with the outer cover removed, two athletic ball inflation needles, a motorcycle fuel filter and a commercially available nebulizer with mask, all connected in series with the plastic medical tubing that is supplied with the nebulizer/mask kit. Air generated by the pump flows into the soccer ball's inflation port and exits the ball through a second hole punctured in the ball with a needle. The gas then flows through the filter and on to the nebulizer and mask. The outer cover of the soccer ball is removed to make it easier to puncture a second hole in the ball.

Fig. 1. Components of our HPN. The outer covering was removed from the soccar ball before the HPN was assembled.

We measured the stroke volume of the bicycle pump (0.207l/stroke) and calculated that approximately 40strokes/min, or a stroke/1.5s, was required to produce the 8l/min goal flow rate. We measured the pressure at 40strokes/min and found it to be approximately 8psi.

The soccer ball functions as a mechanical low-pass compliance filter to smooth the flow/pressure pattern, in order to better approximate the pressure/flow characteristic generated in a commercial, electrically-powered, compressor-type, continuous-flow medical nebulizer. We tested several different balls (basketballs, different sized soccer balls and playground balls) and other compliance elements during our design/development phase of the project before settling on the skinless soccer ball.

We hypothesized that if our HPN produced pressures and flow rates comparable to a commercial nebulizer, with both using a standard nebulizer and mask, then we should expect to produce a comparable particle size distribution. The MIT team measured particle size and particle size distribution using a similar bicycle pump HPN design. Through personal communication and data, the team informed us that, with tested stroke rates between 30 and 100strokes/min, the particle size remained acceptable, 2-15µm over the flow rate range.

III. In-Country Implementation and Testing

A. Cost

Table II shows the in-country cost for replicating our HPN from locally available parts in both Honduran lempira (HNL) and US dollars (USD).

TABLE II. COST OFHPN IN HONDURAS

Component	Cost (USD)
Motorcycle fuel filter	$0.98
Bike pump	$6.10
Soccer ball (size 5)	$7.32
Inflation needles (2)	$0.48
Nebulizer, tubing and mask kit	$2.10
Total Cost	**$16.98**

The parts for the HPN were readily available from pharmacies (the nebulizer, tubing and mask kit) and from hardware stores, grocery/department stores and auto parts stores. The total cost of our HPN in Honduras was USD17. We conducted a nonscientific comparison study using pricing data obtained from the website www.justnebulizers.com (Just Health Shops, Fulton, MD USA). The average price for 45 electrically-powered portable compressor-type (not ultrasonic) nebulizers advertised at that site was USD75 (range USD30-USD590), most excluding the mask. Commercial full-sized nebulizers used in the clinic or hospital setting cost USD200 or more.

B. Testing/Evaluation

During a two-week trip to Choluteca, Honduras, 3-17 May 2014, we constructed and tested our HPN, and compared the performance of our machine to that of a commercial electrically-powered compressor-type hospital medical nebulizer in a small pilot study.

1) Materials and Methods; Fifteen HPN patients and two commercial nebulizer patients participated in this prospective study. Before each treatment, we recorded patient demographic information including age, gender, and non-breathing related health problems. We measured each patient's pre- and post-treatment peak expiratory flow (l/min) with a Wright respirometer. We evaluated each patient's breathing difficulty before and after treatment using a 0-10 linear visual analog scale (VAS, a scale identical to a pain evaluation scale used in pain management), with 0 being no difficulty and 10 being extreme difficulty.

2) Results: Table III and Fig. 2 show the the peak flow measurements recorded in the study.

TABLE III. PEAK FLOW MEASUREMENTS

Patient	Age (yrs)	Gender	Before Treatment (l/min)	After Treatment (l/min)	Change (%)
HPN					
1	4	M	125	160	28
2	40	F	100	220	120
3	62	F	70	120	71
4	40	F	120	170	42
5	69	M	50	80	60
6	7	F	110	150	36
7	28	F	190	245	29
8	40	F	90	150	67
9	1	M	100	150	50
10	53	F	60	150	150
11	14	M	100	200	100
12	10	M	60	150	150
13	5	F	100	150	50
14	41	M	150	250	67
15	1	M	60	100	67
		Mean	**99**	**163**	**72**
		SD	**38**	**48**	**40**
Commercial Nebulizer					
13	6	M	100	250	150
14	79	F	150	200	33
		Mean	**125**	**225**	**92**

SD	35	35	83

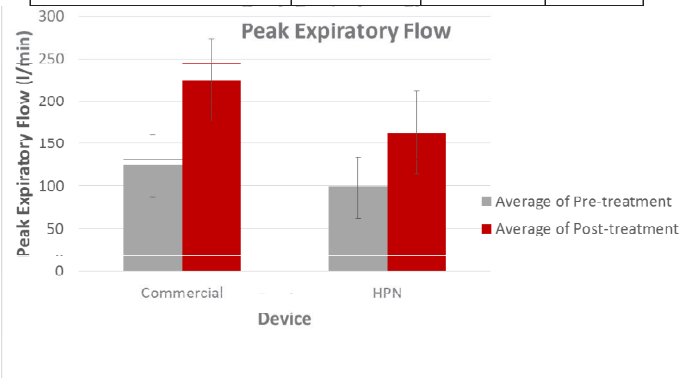

Fig.2. Average (±SD) pre- and post-treatment peak expiratory flow for the HPN and commercial nebulizer.

We set alpha *a priori* at 0.05 for all inferential analyses. We analyzed the peak flow data using a two-way repeated measures ANOVA. Within each nebulizer group (HPN and commercial nebulizer), post-treatment peak flow was statistically greater than pre-treatment flow ($p \leq 0.001$). In this small pilot study, both machines improved the patients' breathing performance. We performed a one-tailed Student's t-test on the percent improvement in peak flow rate following treatment and found no difference in breathing improvement between the two machines ($p=0.288$). Both machines functioned as well in improving the patients' breathing performance.

Not all patients were able to provide a VAS measure of their breathing performance, mostly because several were too young (<4 years old) to understand the process. Those patients who did provided feedback, reported a 2 to 5 point improvement in breathing effort with both machines, on the 0-10 point scale. Qualitatively, all patients tested reported a perceived improvement in their breathing performance with both machines.

IV. Objectives Achieved in this Project

We achieved the following objectives in the project:

- We successfully implemented our HPN in Honduras;
- We tested our HPN vs. a commercial nebulizer and found that our machine was as effective as the commercial machine in improving a patient's breathing performance;
- We built seven HPNs and distributed them to clinics and hospitals in the Choluteca, Honduras metropolitan region;
- We trained local healthcare workers how to build and operate our HPN;
- We provided HPN construction, instruction and user manuals to the local healthcare workers.

V. Discussion

This project was carried out by students as part of the Honduras international engineering service-learning (IESL) program in the College of Engineering at The Ohio State University (Columbus, OH USA). The program is designed to introduce and teach students the concepts of humanitarian engineering through practical, authentic, real-world, hands-on international service-learning experiences. The program follows the well-known service-learning educational model with teaching methodologies aimed at maximizing both the service and the learning for the students [10]. The students assess needs, and then research, design, develop, prototype and test various technologies that meet these needs, in a Capstone-style team format. The students work closely with our in-country partner (World Gospel Mission, Marian, IN USA) as well with local campus partners in this multidisciplinary experience. In this project, the students collaborated with the College of Nursing and the Wexner Medical Center Department of Clinical Engineering. The College of Engineering conducts similar IESL programs in the Caribbean, Africa, Europe and Asia.

In this project, we designed, developed and implemented a HPN for the people in the Choluteca, Honduras region who suffer from various respiratory diseases, and particularly asthma. The device is inexpensive, not only in comparison to commercial electrically-powered nebulizers but also to other human-power machines. It is easy to replicate from common readily available local parts. A person does not need any special skills to build the device. It is simple to use. It treats patients effectively as compared to a commercial medical nebulizer. Because it is human powered, our HPN can be used in regions where commercial nebulizers and the electricity needed to power them are scarce or unavailable. Our machine has been replicated and is currently being used in various clinics in the Choluteca region, now one year after its introduction in the country. This speaks to the device's true value, need, sustainability and acceptance in the Honduran culture.

During our visit to Honduras, we introduced our HPN to a high school teacher who expressed interest in device as a teaching tool for his 10th and 11th grade students. We gave him a machine and manuals so that his students could replicate the HPN as a class hands-on building project. This welcomed encounter was outside the scope of work of the project.

The device and results we report here have several limitations. Although, we report a favorable comparison between our HPN and a commercial nebulizer, our study was small. It was limited by the time we had to collect data during our two-week in-country visit. More data are needed to verify our performance findings.

We believe that some improvements can be made in the design of the HPN. For instance, the overall packaging of the components of the machine could be improved to improve the machine's long-term durability. We had some issues regarding bicycle pump wear and had to resort to lubrication to improve pump function. A more durable hand or foot pump would also improve the device's durability. In addition, the soccer ball could be connected in parallel in the pneumatic circuit, rather than in series, so that a second hole would not be required in the ball. This modification would require a T-connector that incorporates the inflation needle, but would eliminate the need to remove the ball's outer cover. Other compliance elements, other than a soccer ball, could be tested as well.

In conclusion, we developed and implemented a technology, namely a human-powered nebulizer following the principles of humanitarian engineering, which has directly improved the well-being of people in an under-served community but who previously lacked the means to effectively address the problem.

ACKNOWLEDGMENT

The authors thank the following people for their kind technical help and guidance with this project:

- Duane Hart, The Ohio State University Wexner Medical Center Clinical Engineering Department, Columbus, OH USA;
- Kathleen Stone, The Ohio State University College of Nursing, Columbus, OH USA;
- Angie Overholt, World Gospel Mission, Choluteca, Honduras CA.
- Anna K Young, Massachusetts Institute of Technology, Cambridge, MA USA

REFERENCES

[1] Jerry A Dorsch, Susan E Dorsch. Understanding Anesthesia Equipment, 4th ed., Williams and Wilkins, Baltimore, MD, 1998, pg. 299.

[2] Warren H Finley. The Mechanics of Inhaled Pharmaceutical Aerosols: An Introduction. 1st ed., Academic Press. San Diego, CA, 2001, Chapter 8.

[3] Christopher O'Callaghan, Peter W Barry. The science of nebulised drug delivery. Thorax 1997;52(Suppl 2):S31–S44 S31.

[4] WHO: Honduras. http://www.who.int/nmh/countries/hnd_en.pdf.

[5] Honduras: WHO Statistical Profile. http://www.who.int/gho/countries/hnd.pdf?ua=1.

[6] Different Kinds of Nebulizers for Various Needs. 2014 January 29. http://ncsuksa.org/xe/club_board/346259.

[7] Medical Devices research. 2014 January 27. http://www.marquette.edu/engineering/biomedical/research_devices.shtml.

[8] http://www.who.int/medical_devices/innovation/med_dev_not_yet_5.pdf.

[9] DIY Medikit nebulizer. 2014 February 3. http://littledevices.org/2013/08/10/diyneb/.

[10] Mariantonieta Gutierrez Soto, Roger Dzwonczyk. Maximizing Service and Learning in an International Service Learning Program. 2015 IEEE Global Humanitarian Technology Conference. Seattle, WA USA.