Engineering World Health: Aspirator

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Abstract

Medical aspirators are suction devices used to remove mucous and other bodily fluids from a patient. Many developing world hospitals do not possess aspirators because they can not afford or repair the current devices on the market. The goal of this design is to create a less expensive, locally repairable, and electricity independent alternative to current medical aspirators. The design should provide the broadest range of possible uses for developing world hospitals. The prototype built this semester offers optimal affordability and availability for third world construction. In order to be implemented as an effective medical aspirator, the design must be optimized in order to maximize the vacuum and flow rate.

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Problem Statement

Engineering World Health (EWH), a non-profit organization through Duke University, has asked for help in designing an inexpensive medical aspirator that can be built and repaired from locally available parts and expertise for developing world hospitals. Furthermore, the device must be able to function semi-autonomously off electricity since a constant electric power supply will not always be available. Developing hospitals will likely be able to afford only one aspirator, so the design must function under the broadest range of applications possible. Further research into current medical aspirators gave a basis to create further design constraints including pressure ranges and flow rates. Ultimately, EWH requires an aspirator design that can be built completely from locally available resources that will meet all the relevant criteria for functioning in a developing world hospital.

Background Information

Aspirating equipment can be found in almost any hospital, ambulance, or dental clinic in the United States. A medical aspirator is simply a suction device used to remove mucous, blood, or other bodily fluids from a patient **(Figure 1)**. The apparatus will generally include disposable suction tips and a removable collection receptacle. This device is a necessary tool in dental practice, liposuction and most surgical procedures. Depending on their exact function, aspirators are generally powered by 120V AC outlets, batteries, or a combination of the both. The size and portability of the device

Figure 1: Tip of surgical aspirator. Source: http://www.valleylabeducation.org/esself/Pages/esself23.html

are also determined by its application. Sizes can range from 11.4 lb, battery powered hand held devices to 70 lb stationary surgical units (Gomco Suction Equipment, 2006). Aspirators currently on the market are designed for use in modern, state of the art medical environments. Differences in modern and developing hospitals render these models impractical for use in third world countries.

Third world hospital conditions are radically different from their modern American counterpart. Electricity is spotty at best for developing world hospitals and therefore equipment cannot depend on a constant supply of electricity. Trained medical professionals are in short supply, requiring devices to have the simplest user interface possible. Limited space is another concern, as most rooms are overcrowded with patients, staff, and equipment (Hill D 2005).

Current Devices

There are many medical aspirators on the market today with a wide variety of functions. In the $500-600 price range, Gomco® provides a line of portable aspirators (Models G180, 405 & 300) that use diaphragm compressors to create vacuum ranges from 0-600 mmHg and flow rates of 30 liters per minute (lpm). Dimensioned at 12x9x12 inches, these devices weigh around 14.5 lbs. Specialized stationary aspirators are available for uterine, thoracic drainage, endocervical and dental operations. Most are powered via 120V AC current and range in weight from 50-70 lbs. Thoracic and thermotic drainage pumps operate under low pressure and low flow conditions (0-50 cm H20, 2.3 lpm) to regulate drainage levels in post-operative care. Endocervical aspiration alternatively requires high pressure ranges (600 mmHg) and high flow rates (20-30 lpm) for brief intermittent use (Gomco Suction Equipment, 2006).

All of these designs, however, are inaccessible to a developing world hospital for several reasons. The most obvious limitation of these devices is their price; even the cheapest models exceed EWH's projected 100 dollar budget. In addition, the specialization of current devices provides another budgeting concern. Most aspirators on the market are designed for a very specific function. A hospital that can only afford a single aspirator would need the broadest range of applications possible. Finally, these devices cannot be repaired with locally available parts and expertise. Advanced circuitry and specially manufactured parts render these devices irreparable in developing world hospitals.

Design Constraints

Engineering World Health provided only a couple of constraints to follow and left the rest of the design quite open-ended, creating the need to establish additional guidelines. The biggest focus of the aspirator design is that it needs to be constructed entirely from locally available materials in third world countries. These materials can include anything already on hand in the hospitals, as well as anything that can be obtained from the surrounding environment, such as car batteries, simple motors, and tubing. The design must include autoclavable suction tips for easy sterilization. The final goal of the semester is to produce a working prototype for fewer than 100 dollars, as specified by EWH. Since the apparatus will be used in a hospital setting, the final product must be safe for sterile use in the operating room. The final device should not rely solely on electrical power, due to its inconsistent availability in third world countries

In addition to these constraints, new ones were created relating to the vacuum pressure range and flow rate. After researching various current aspirators on the market, it was agreed the design should have an adjustable vacuum pressure range of 0–550 mmHg below the standard sea level atmospheric pressure of 760 mmHg. The maximum flow rate of material and liquids through the tubes should be adjustable from 0-30 Liters per minute (lpm). These specifications are based off an aspirator (Model-IRC1135) produced by Medical Supply 4U (Aspirator Suction Machine, 2007). (A full product design specification is available in ***Appendix A.***)

Design Alternatives

Each design has the same basic setup with a varying vacuum source. Each includes autoclavable suction tips connected with tubing to a collection chamber where fluids and other materials accumulate. Another tube joins the collection chamber to the vacuum source.

Design 1: Water Hourglass Design

Overview

The first design relies on water flow through a Venturi to create the partial vacuum needed for uptake of fluids. Inspiration for this design came from a typical hourglass, but in place of the glass and sand will be two water jugs (think Culligan water coolers) and water. The water containers will be attached to a rigging that can be inverted 180 degrees and locked into place so that when water completely flows out of one container, the system can be flipped and the process repeated. In between the two water jugs will be a system resembling a Venturi **(Figure 2)**. The Venturi effect is a special case of the Bernoulli principle where fluid flows through a constricted (decreased diameter) tube or pipe. Fluid must speed up at this constriction, reducing its pressure, which in turn produces a partial vacuum in the tube connected to the constriction (as shown by the change in fluid height, h, above). In this design, the tube connected to the Venturi constriction would be connected to the collection chamber. Another hose from the collection chamber would have the autoclavable tip and would be where fluid enters. Ultimately, the water flow through the Venturi constriction generates a partial vacuum responsible for drawing fluids in through the autoclavable tip for deposit into the collection chamber.

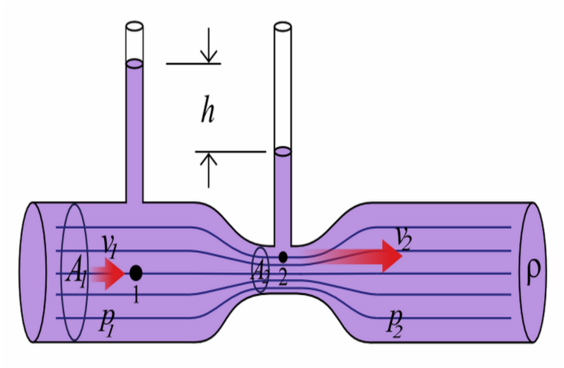


Figure 2: Venturi Pipe
As the velocity increases through the constriction, a partial vacuum is generated as shown by the altered height (h) of the liquid. Source: www.wikipedia.org

Advantages and Disadvantages

A big advantage of this design is that all parts should be locally available and construction is relatively simple to complete. Access to basic tools should allow almost anyone to put together the final design. The vacuum source of water is readily attainable at the hospitals in third world countries. The water as a vacuum source in this design is reliable, reusable, and should not have to be replaced very often. Overall, the materials needed in this assembly are relatively inexpensive and should come in well under the 100 dollar limit.

However, a big problem with this design is that the vacuum generated will not be sufficient to pull in fluids at the rate specified above. The maximum vacuum generated by Venturi vacuum pumps researched was 252 mmHg, which falls well under the desired specifications (Venturi Vacuum Generators, 2007). In addition to a weak vacuum source, the overall construction of this design may be too bulky for an operating room environment. There is already limited space and introducing such a large machine could be cumbersome to the work doctors and nurses need to accomplish.

Design 2: Foot Pump

Overview

Whereas the first design utilized the Venturi effect to create a vacuum, the second design relies solely on a mechanical approach to solving our problem. The fundamental basis of this design is modeled from a foot pump typically used to blow up an inflatable raft **(Figure 3)**. These foot pumps are human-powered devices, and unlike other instruments used to inflate objects, these foot pumps do not use any sort of fan or electric pump to accomplish their goal. A simple design, these pumps consist only of an air chamber and a pair of one-way valves. This sealed air chamber is typically in the shape of a wedge, allowing for an easier, more ergonomic angle of pumping with the foot. The vertical walls of these chambers are flexible. Thus, when the user steps on the top of the chamber and

Figure 3: Foot Pump. Used to blow up inflatable objects. Source: www.altrec.com

applies a portion of their weight to the top of it, it collapses. This collapsing or contracting motion of the chamber forces air to be evacuated out of the one-way air-release valve. Usually, this air is directed through a hose connected to an inflatable object and proceeds to fill this object with air. However, for our purpose, we are not necessarily concerned with this step of the process.

After the compression stage comes the phase of restitution. Once the pump's air chamber is collapsed and the user removes the pressure applied by their foot, the chamber walls have a desire to return to their original position. In addition, the process is usually supported by some sort of spring inside of the pump which forces it back to its original position. However, the sealed chamber is now a vacuum because the air which previously occupied the chamber was evacuated during the contraction stage. To facilitate its return to form, air is allowed into the vacuum via the one-way inlet valve. This vacuum will be harnessed by connecting the fluid collection chamber to the outside of the one-way inlet valve on the foot pump. Thus when the foot pump draws air in to reconstitute its original form, it will be drawing air in through the autoclavable tip and the fluid collection chamber.

Advantages and Disadvantages

This design hosts quite an impressive list of benefits, the first of which is its simplicity. Being such a simple design proves to be very important, and promotes its usefulness on multiple levels. Being made of only a few parts, this device could easily be constructed without many complications. If any problems are encountered during use, it would not be difficult to troubleshoot what the cause of the problem is. Also, because it is such a basic design, the costs of materials associated with assembling this device are minimal.

Being a completely human-powered alternative, its usability is completely independent of a need for electricity, which is extremely beneficial. In this respect, the foot pump aspirator is particularly applicable for hospitals in especially secluded areas or undeveloped regions.

However, with these advantages follow certain downfalls. Because of its reliance on man-power, it is a physically demanding device. In order to provide constant suction, this machine requires continuous effort to pump the air chamber repeatedly. Even with this consistent effort of human-energy, the device is unable to supply a continuous vacuum. It is limited strictly to short, repeated burst of suction. As a result, its clinical value is greatly reduced. Inconsistent airflow is not acceptable for all applications and the overall level of suction generated is most likely too weak to be effective. This is a result of the fact that the amount of vacuum that can be produced is limited by the restitution force of the pump itself, not the strength of the user. This design is also inconvenient, as it would most likely require a separate person to pump the device while the health care provider maneuvers the tip of the aspirator.

Design 3: Electric Vacuum Pump

Overview

Our final design combines the power of electricity with mechanical principles to generate a powerful, consistent vacuum source. The source of this vacuum will start at a small electric motor, in the range of 3-8 AMPS. This direct current (DC) motor will run on a 12 volt car battery. Connected to the electric motor will be an adapter to transform the rotating motion into linear movement of a connecting rod. The rod will then be attached to a system composed of a diaphragm or piston and pair of one-way valves. This system mimics that of a commercial vacuum pump **(Figure 4)**. As the connecting rod oscillates up and down, it will contract and expand the diaphragm system. This motion is similar to the foot pump design in that the compression and relaxation of this sealed diaphragm system causes air to be exhaled through the release valve and then new air be taken in through the one-way intake valve. The vacuum created at the intake valve is then connected through an air-tight hose connection to the fluid collection chamber, and extended throughout the suction tip.

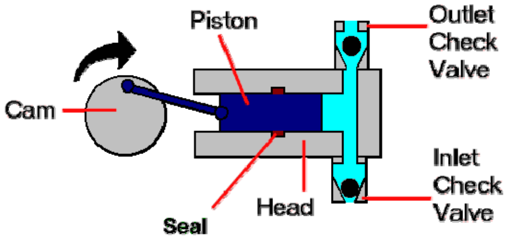


Figure 4: Commercial Vacuum Pump. Our system mimics these principles. Source: www.lcresources.com

The motor's high-speed rotation, which converts to multiple linear oscillations per second, provides a high rate of contractions and expansions of the diaphragm. As a result, the vacuum created flows at a near-continuous rate, and thus the suction realized by the operator is very consistent.

Advantages and Disadvantages

Because this design uses a standard 12 volt car battery as its source of energy, the aspirator is very versatile. This power source is an item that is both relatively standard and widely available throughout the world, including developing countries. In the absence of electricity, the battery can be charged by gas or manual power. In the addition to being charged a number of different ways, a car battery has enough stored potential energy to provide a strong vacuum for the duration of an operation. Similarly, this design is powerful enough to generate flow rates in our targeted range of 0-30 liters per minutes.

Continuous suction and reliable flow are two important features required for an aspirator to be useful in any hospital. This design satisfies both of those criterions and thus is also able to provide the broadest range of application possible.

There are some setbacks to the electric vacuum pump solution, however. It’s a complicated design, which makes it more difficult to build and repair if necessary. Using a car battery as a power source is also not a perfect answer because it can only store so much power. When it runs out the battery needs to be charged, which might not always be easy. However, it does solve the problem of inconsistent electricity in third world countries.

Design Matrix

A design matrix **(Table 1)** was developed from the three unique designs to rate advantages and disadvantages based on several crucial criteria: power availability, construction resources, pressure, hospital integration, reliability/safety and cost. For each of the criteria, the three designs are each scored either on a scale between zero and ten or on a scale between zero and five depending on the importance of the criteria. The criteria of greater importance are given a wider range of scale. The maximum score that can be assigned to a criterion is indicated in parenthesis. The highest score corresponds to the most favorable design based on the particular criteria.

As stated in the Problem Statement, one of the main constrains for the project is that all materials required to build, power, and repair must be locally available in third world countries. The availability of power sources strongly disfavors the electric pump design due to its dependency on electricity, which is not guaranteed to be in consistent supply. The availability of construction resources also disfavors the electric pump design because an electric motor is more complex than the other two design constructs and therefore is less likely to be available. The complexity is also proportional to the cost of the device. Despite these disadvantages, the electric pump satisfies the next three criteria better than the other two designs. First of all, the pressure generated by the electric pump is much more consistent than the foot pump where the airflow is driven by human motions. At the same time, the electric pump is capable of generating a vacuum pressure much greater than the water hourglass design that applies the Venturi effect. In addition, the electric pump is a more practical instrument for a hospital environment than, for example, the water hourglass design, which is bulky and can be obstructive. Finally, the electric pump, because the power source is more controlled and consistent, is the most reliable and safe option. The addition of scores indicates that the electric pump is the most favorable design even though it has its own share of disadvantages. With a sufficient design, these shortcomings will be outweighed by the many advantages of the device. The design must produce an aspirator that is consistent, powerful, practical, and reliable because the safety of patients is the most essential criteria for any medical instrument.

	Foot Pump	Water Hourglass	Electric Pump
Power Availability (10)	7	8	4
Construction Resources (10)	9	7	5
Pressure (10)	2	4	9
Hospital integration (5)	4	2	4
Reliability/ Safety (10)	1	5	8
Cost (5)	5	4	3
Total	**28**	**30**	**33**

Table 1: Design Matrix of the three design alternatives

Final Design

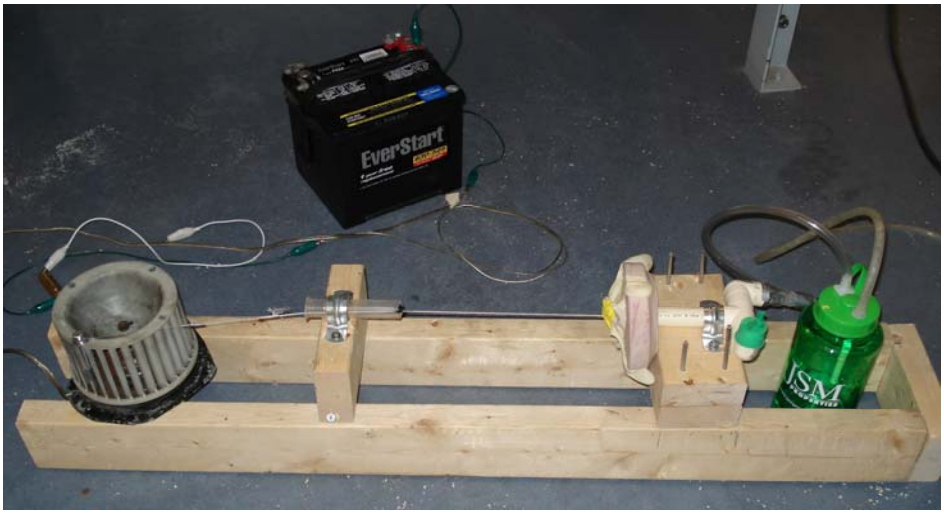


Figure 5: Overall Design

The main components of the final design include a 12 V car battery, fan motor, diaphragm system, pair of one-way valves, fluid collection chamber, and tubing with an autoclavable tip **(Figure 5)**. The battery provides DC voltage to turn the fan motor. The radial motion of the fan is converted to linear motion by means of a string. This linear motion oscillates the diaphragm, creating a continuous cycle of air flow into and out of the diaphragm compartment. The air flow into the one way inlet valve creates a partial vacuum in the attached tubing system. A vacuum is therefore created in the collection chamber which is used to draw fluid in through the opening in the autoclavable suction tip.

Due to inconsistent electricity in developing world hospitals, the power source for the design runs independent of AC power. The 12V DC car battery provides enough energy to power the fan motor and allows the aspirator to be run for at least two hours without recharging. When the battery dies, it can be recharged using a car or with AC power when it is available. The car battery can easily be salvaged from an abandoned vehicle.

Figure 6: Circuit
Fan motor not pictured

Standard wires complete a simple circuit consisting of the battery, a 2 ohm power resistor, and a fan motor connected in series **(Figure 6)**. The power resistor decreases the power reaching the motor and is necessary to slow the rotational velocity. The 2 ohm power resistor can be substituted with four 10 ohm light bulbs in parallel. These light bulbs give an equivalent power resistance of 2.5 ohms and are readily obtainable. Once the circuit is connected, the fan motor runs at a more manageable speed. Also, by being able to change the number of light bulbs used in the circuit, this feature allows the users to vary the amount of resistance and thus optimize the speed of the motor to vary the rate of aspiration.

The fan motor is salvaged from the heater blower of a car. Any other motor that provides a similar circular rotation would also work, as long as it is able to pull on the diaphragm with enough force. A bolt and washer is glued, tied, and/or taped through the outer rim of the fan that is attached to the gear of the motor **(Figure 7)**. Tied to the washer is an approximately two foot long string. The washer allows free rotation and prevents the string from coiling up and breaking.

Figure 7: Fan Motor
Bolt, washer, and string attached through outer rim of fan

The string is fed through a syringe casing that is mounted at the same height as where the string is tied to the washer. The syringe is approximately 1/3 of the way to the diaphragm system. The syringe refines the motion of the string, eliminating unnecessary perpendicular motion and increasing the linear pull on the diaphragm. The other end of the string is tied to a rubber balloon which is part of the diaphragm system.

A cylindrical lid (~3 inch radius) from a food container is fitted around the lone end of one inch diameter, T-shaped PVC pipe, acting as the base of the diaphragm. A thick rubber balloon is stretched over the lid to create the diaphragm and the string is tied to the tip. A layer of rubber glove is super-glued to the balloon and over the string for added support **(Figure 8)**. The center of the diaphragm (where the string is tied) should also be the same height as both the syringe and the washer-string connection to prevent friction and wear on the string.

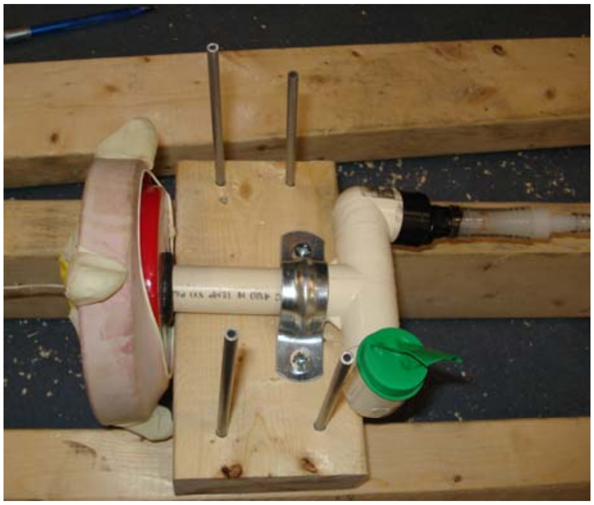


Figure 8: Diaphragm and Valves
Left: diaphragm; Right: green output valve, black inlet valve

The outlet one-way valve is the stem of a balloon glued half shut and stretched over one end of the PVC pipe. The inlet one-way valve is a check valve obtained from the bulb of a sphignomonometer. This is located in the tubing adapter attached to the other PVC pipe opening. From this tubing adapter at the input check valve, a half-inch diameter, non-collapsible tube (~2 feet) is connected which leads to the collection chamber **(Figure 8)**. The tubing must be stiff so the vacuum generated does not collapse the tubing and cut off air flow.

The collection chamber shown in **Figure 9** is an air tight, hard plastic water bottle (e.g. Nalgene). Holes were drilled into the lid and fitted for tubing adapters. Attached to the air/fluid intake tube adapter is a pen shell or other long cylinder object, such as a straw, that will direct aspirated fluid to the bottom of the collection chamber and thus prevent liquid uptake into the diaphragm system.

Finally, a longer (~4 feet) half-inch diameter, non-collapsible tube is attached to the collection chamber and connects to the autoclavable pipette suction tip **(Figure 9)**. The tip is cut so a wider opening can take in water at a faster rate (see testing). The pipette tip is a hard durable plastic, that can withstand the high temperature and pressure of the autoclave machine.

Figure 9: Collection Chamber, Tubing, and Autoclavable Tip

The entire system is mounted on a frame of 2x4 boards to hold each of the individual components in its correct position in relation to the other parts. The placement of the motor and diaphragm should be such that it maximizes the amount of air flow created by system (determined through trial and error). The collection chamber is not permanently attached to the frame. This allows it to be removed, emptied, and cleaned. The battery is also not attached to allow easy removal for recharging. The entire system can be placed on a cart where it can be easily moved throughout the operation room. Ideally, the cart would be as low to the ground as possible. This would decrease the amount of obstruction and allow easy storage under tables, beds, etc. As an added benefit, this will maximize the flow rate of the aspirator by using gravity to create a siphon effect.

Safety is one of the most important aspects of any medical device. It is important that all pieces that may come into contact with patients have the ability to be sterilized. The pipette tip and tubing used to aspirate is completely autoclavable. Because of the simple user interface of the aspirator, it is easy to use and thus minimizes the possibility of a user-related error. Sterility can be maintained by using long tubing between the collection chamber and autoclavable tip, increasing the distance between the patient and any non-sterile parts.

Cost and Availability

The cost of the prototype was estimated at $49.50 for parts purchased in the U.S. **(Table 2)**. This is believed to be a high estimate, as many of the parts used can be easily salvaged, free of cost. Furthermore, the simplicity of the design allows parts to be readily exchanged, depending on what materials are available. The final design instructions will include a list of possible materials that would suffice for each part of the aspirator. This will ensure the hospital is purchasing as few parts as possible for the construction of the device. Depending on what parts can be salvaged, a total cost of $20-30 is a practical estimate of actual cost, which is well under EWH's $100 budget limit.

The design also meets the EWH's requirement that all tools and skills necessary for the construction of the device are available in the 3rd world country. The only tools required for building the aspirator are a hammer, nails and glue. No special training or expertise is required at any step of the aspirator's construction. The string design eliminates the need for air tight pistons, a precisely machined component of many modern aspirators. Any wiring involved in the construction of the aspirator would be explained in detail, and would require no significant understanding of electronics or circuitry. A hospital employee involved with construction or maintenance could easily assemble this device with standard, readily available tools.

Table 2: Shows costs and 3rd world source for each part used in the prototype

Part	**Cost**	**3rd World Source**
1" PVC pipe	$1.09/foot x 2 feet = $2.18 Source: Home Depot	Plumbing equipment
Lab Gloves	$.28 x 4 = $1.12 Source: medicalsupplyco.com	Operating room
DC Fan Motor	$5.00 Source: Moemart Salvage	Salvaged automobile
12 V Battery	$20 Source: Moemart Salvage	Salvaged automobile
Pipet Tip	$.04 Source: Fisher Catalog	Hospital lab
Plastic Syringe	$.75 Source: Ax-man Surplus	Operating room
2x4 Lumber	$.80/foot x 6 feet = $4.80 Source: Home Depot	Natural environment Abandoned building

Nails/Screws	$.20 x 8 = $1.60 Source: Home Depot.com	Abandoned building Construction material
Water Bottle	$4.00 Source: Walmart.com	Household item
Tygon® Tubing	$1.09/foot x 6 feet = $6.54 Source: medicalsupplyco.com	Operating room Salvaged automobile
2 Ω Power Resistor	$1.09 x 2 bulbs = $2.18 Source: Home Depot	Two 60 watt light bulbs (wired in parallel)
Check Valve	$.99 Source: Ebay.com	Sphignomonometer Operating room
Wire	$.15/foot x 2 feet = $0.30 Source:Walmart.com	Salvaged automobile Electronic devices
Total	**$49.50**	

Testing and Results

Evaluation of the prototype was done by running tests on the device to measure its performance. Tests were completed that measured two values: the liquid flow rate and the vacuum. Liquid flow rate represents the volume of liquid that can be aspirated over the time it takes to do so (usually measured in liters/min, or lpm). This value is important because it corresponds to the maximum amount of bodily fluid that could be evacuated in a period of time, such as how fast a certain amount of blood could be removed

Table 3: Flow rate testing results

Large Tip				
trial	Liters	Seconds	Flow (L/s)	Flow (L/m)
1	0.54	20	0.027	1.62
2	0.5	20	0.025	1.5
3	0.52	20	0.026	1.56
4	0.54	20	0.027	1.62
5	0.56	20	0.028	1.68
6	0.52	20	0.026	1.56
Mean			0.0265	1.59
SD			0.001049	0.062929
SE			0.000428	0.02569

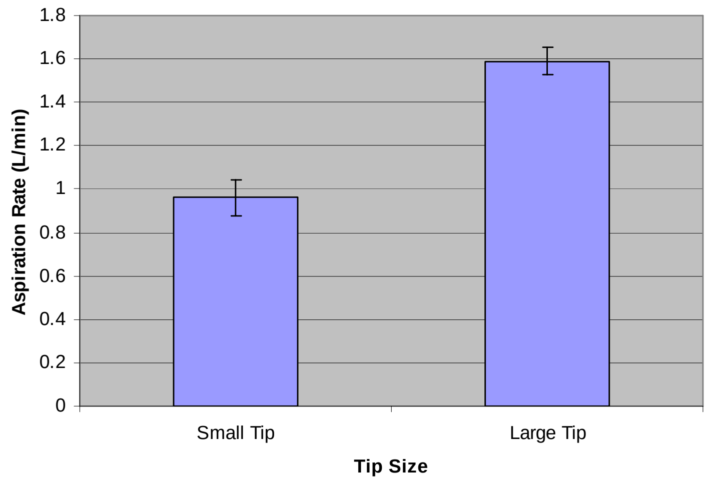
Small Tip				
trial	Liters	Seconds	Flow (L/s)	Flow (L/m)
1	0.28	20	0.014	0.84
2	0.32	20	0.016	0.96
3	0.32	20	0.016	0.96
4	0.34	20	0.017	1.02
5	0.36	20	0.018	1.08
6	0.3	20	0.015	0.9
Mean			0.016	0.96
SD			0.001414	0.084853
SE			0.000577	0.034641

during a surgery.

To measure the liquid flow rate of the aspirator, the tip was submerged in an open container filled with water. Time trials began at the start of suction, just after the battery was connected to the aspirator. After 20 seconds had passed, the volume of liquid aspirated was measured by the amount of water that accumulated in the collection chamber. The water bottle used as the collection chamber was pre-marked with levels of 100mL, thus allowing analytical measurement of liquid to increments of 20mL. Precautions were taken throughout the testing to ensure the pool of water was level with the collection chamber, as to eliminate the possibility of a siphon effect influencing the flow rate.

Twelve trials of 20 seconds each were run to measure the liquid flow rate. Within these twelve trials, six were done with a small pipette tip and six were performed with a larger pipette tip. Results are shown above in **Table 3**. The average flow rate of the small tip was just less than one liter per minute (0.96 lpm), while the large tip averaged over a liter and a half per minute (1.59 lpm), as shown in the graph of **Figure 10**. Values were relatively consistent within each given set of trials.

Figure 10: Average Flow Rates



The other value tested was the amount of vacuum generated by the aspirator. To measure this, the aspirator tip was connected to a pressure monometer with the device running. A vacuum of 3.0 inHg was created, which corresponds to about 76 mmHg below standard atmospheric pressure. While the results testing are less than the target values established in the design criteria, they represent an excellent proof of concept, especially for a device built completely from salvaged materials with no machining or advanced fabrication. In addition, even operating with maximum values approximately 1/10 those of commercial aspirators, this design is still effective. The flow rate of 1.51 lpm still moves a substantial amount of fluid and as such would be useful in a hospital setting.

Future Work

The resultant design from a semester's worth of work has undoubtedly left room for improvements. With the current prototype built and tested, objectives have been identified to better incorporate the aspirator into third-world hospitals. The prototype will be optimized by increasing the vacuum's capacity, consistency, and range.

The current airflow of the aspirator is limited in its maximum rate, lacking consistency and being restricted at one operational speed. Attempts to raise the volume of air displaced per stroke of the motor by increasing the distance between the motor and the diaphragm resulted in tensions too high for the motor to pull. Mechanically, not all of the rotational energy of the motor was transferred to the linear translational energy required to pull the diaphragm. Therefore, the geometry of mounting the motor and diaphragm could be maximized to use the available power most efficiently.

In order to accommodate the increase in energy output of the linear motion, the materials, especially the diaphragm and the string, must be able to withstand the force applied to them. The current diaphragm is made from a sheet of rubber balloon and a layer of disposable laboratory glove. Although economical and locally available, it is not strong and durable enough to guarantee to be consistent over an extended period of time. Any breakage in the diaphragm would result in an air leak, and in turn, loss of consistent suction. More importantly the string, being the only linkage to transfer the energy from the motor to the diaphragm, must be able to withstand the tension force and the frictional force rubbing against other surfaces. Because of these considerations, the current design can only operate with a significant amount of power dissipated into resistors to reduce the stress on the string and diaphragm. As a result, higher rotational power is sacrificed to compromise for consistency. Stronger and more durable materials will undoubtedly be needed in the future for an improved design.

The last modification involves the addition of a system that can control the rotational speed of the motor. The EWH aspirator design aims to have the broadest range of applications possible. To satisfy the need of different medical procedures, the ability to adjust the airflow rate is essential. By varying the resistance in the circuit, the amount of power delivered to the motor will vary, resulting in change of rotational speed. Resistance can be adjusted by introducing a variable resistor or a switch connected to resistors (light bulbs) of different values.

It is sincerely desired that, with funding from EWH, the modifications of the current prototype can be made and tested. Once the design is optimized in its maximum capacity, consistency, and control, complete instructions will be devised so that with little expertise, an aspirator can be built locally to meet the needs of developing hospitals.

Conclusion

It is evident, that the prototype developed this semester is an excellent starting point to create an effective aspirator for use in 3rd world countries. The low cost and high availability of all materials used make this device accessible for hospitals with even the most limited of resources. The simplicity of the device makes it ideal for local construction and repair. As expected, after only a semester's work, there is still vast room for improvement in our design. In order to function as an effective medical aspirator, the device must produce significantly higher and adjustable vacuum and flow rates. As previously described, these are improvements that could be made to the current design without an unreasonable amount of time or energy. With the continued support of our client we wish to further improve our design and submit a set of detailed instructions to EWH so that it may be used to assist any developing hospital that may benefit from our ideas.

References

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Appendix A - PDS

Product Design Specification

Engineering World Health Aspirator (February 2007)

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Problem Statement

Most developing world hospitals do not possess operating suction machines. The main problems are the lack of available spare parts, the cost of a replacement unit, and dependence on consistent electricity. The objective of this project is to design a suction machine that can be manufactured from locally available materials (and therefore repaired using locally available materials and expertise).

Client Requirements:

- Device should run on batteries, electrical power (when available) and hand (or foot) power.
- Should provide the broadest range of applications possible.
- Device should include autoclavable suction tips.
- Must be completely manufactured from locally available materials for under $100.

Design Requirements

1. **Physical and Operational Characteristics**
    a. *Performance requirements:* Must perform at a level acceptable for surgery and have a variable level of pressure.
    b. *Safety:* Must be safe for use on human surgeries and must have an autoclavable tip.
    c. *Accuracy and Reliability:* Must be able to reliably provide suction throughout an entire surgery or operation.
    d. *Life in Service:* Must last long enough to be economically viable and worth the time and energy to build. Locally repairable.
    e. *Shelf Life:* Storage in third-world hospital conditions.
    f. *Operating Environment:* The system will be used for surgery and operations.
    g. *Size:* Must not interfere in operating room procedures or with staff.
    h. *Weight:* Able to move in and out of operating room
    i. *Materials:* Completely manufactured by locally available parts.
    j. *Aesthetics, appearance, and Finish*: Must be clean.

2. Production Characteristics

a. *Quantity:* Create instructions to build locally in any desired quantity.
b. *Target Product Cost*: <$100 in locally available materials.

3. Miscellaneous

a. *Standards and Specifications:* Vacuum pressure range of 0 – 550 mmHg and a flow rate range of 0 – 30 lpm.
b. *Customer:* Needs to run and power device with varying electricity and limited resources.
c. *Competition:* Medical aspirators are widely available in developed countries. Our goal is to provide a cheap alternative that can be locally built and repaired in third world countries.