Engineering World Health: Aspirator

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Abstract

Medical aspirators are suction devices used to remove mucous and other bodily fluids from patients. Many developing world hospitals do not possess aspirators because they cannot afford or repair the current devices on the market. The goal of this design is to create an inexpensive, 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 end result of this work will be to produce a detailed, easy to read set of instructions that will include how to build, test, and operate the device.

Table of Contents	Page

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. 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. Pressure and flow rate ranges should be comparable to current medical aspirators on the market. Ultimately, EWH requires a detailed set of instructions for the construction, testing and use of an aspirator 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 generally includes 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 both. The size and portability of the device are also determined

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

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 between 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 counterparts. 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 this semester is to produce a working prototype for less than 100 dollars and a set of detailed instructions, 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.

Additional design constraints were also created for the vacuum range and flow rate. After researching various current aspirators on the market, it was agreed the design should have an adjustable vacuum 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.***

Continuing Design

The main components of last semester's design include a 12 V car battery, a fan motor, a diaphragm system, a pair of one-way valves, a fluid collection chamber, and tubing with an autoclavable tip **(Figure 5)**. The battery provides power 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,

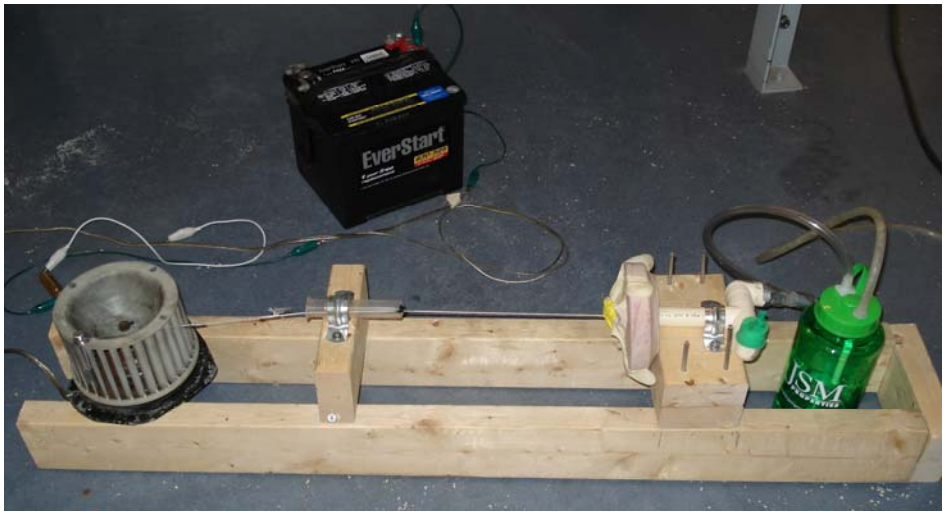


Figure 5: Overall Design

creating a continuous cycle of air flow into and out of the diaphragm compartment. The air flow into the one way inlet valve creates suction in the attached tubing system. Fluid can then be drawn in through the autoclavable suction tip and collected in the collection chamber.

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 another car or other various ways if AC happens to be available. The car battery can easily be salvaged from an abandoned vehicle.

Figure 6: Battery and Power Resistor in Series

Typical wires complete a simple circuit consisting of the battery, a 2 ohm power resistor, and a fan motor 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

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

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 the same 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 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.

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 side-to-side motion and increasing the linear pull needed for 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 PCB pipe, resulting in 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.

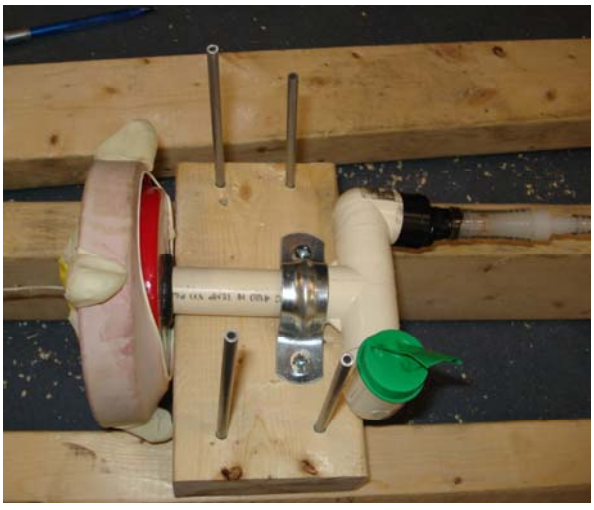


Figure 8: Diaphragm and Valves
Left: diaphragm; Right: green output valve, black inlet valve

The outlet one-way valve is the stem of a balloon glued half shut and stretched over one end of the PCB 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 PCB pipe opening. From this tubing adapter at the input check valve, a tube is connected which leads to the collection chamber **(Figure 8)**.

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, the design uses a pipette tip as the autoclavable suction tip **(Figure 9)**. The tip is cut so a wider opening can take in water at a faster rate (see testing). While the pipette tip is plastic, it is a hard 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 its advantage.

Safety is the most important aspect of any medical device. It is important that all pieces that may come into contact with patients have the ability to be sanitized. The tip used to aspirate is completely autoclavable, a process used to sterilize medical equipment. Because of the simple user interface of the aspirator, it is easy to use and thus minimizes the possibility of a user-related error. In addition, construction of the device is relatively simple and can be completed in a timely manner.

Cost and Availability

The cost of last semester's 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 iswell 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 a 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 aspirators 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 in electronics or circuitry. A hospital employee involved with construction or maintenance could easily assemble this device with standard, readily available tools.

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**	

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

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 pressure. 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 during a surgery.

To measure the liquid flow rate of the aspirator, the tip was submerged in an open container filled with water. Time

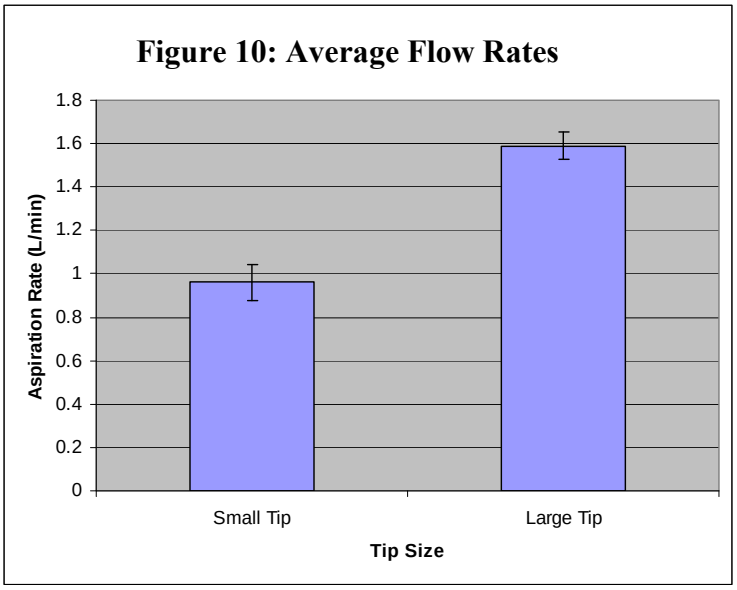
Table 3: Flow rate testing results

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

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 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.



The other value tested was the amount of vacuum pressure 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. This value is equal 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.

Three Major Improvements

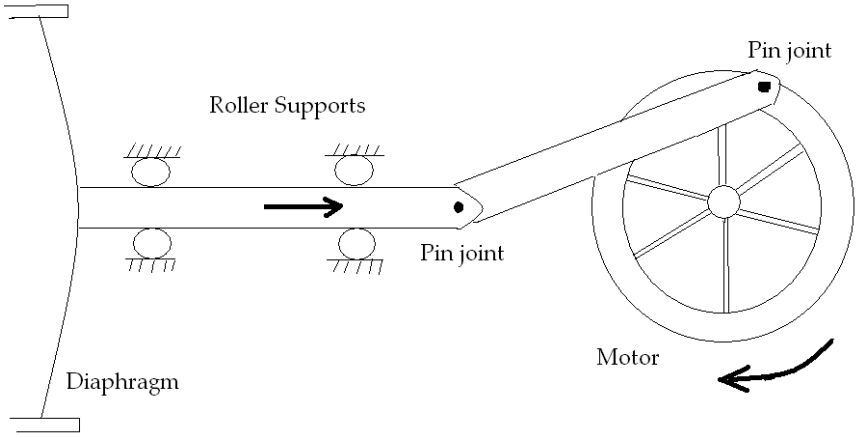
Although the original prototype is functional, the following three major areas require improvements before the final instructions can be written up: the vacuum source, the one-way valve design, and modifications for hospital integration.

Improvement 1: The Vacuum Source

The car battery and the fan motor both satisfy the design constraints and are relatively efficient, so the two major components of the vacuum source needing improvements are the diaphragm attachment mechanism and the diaphragm itself.

Last semester, the diaphragm was attached to the motor by a string. A string can only exert tension force and not compressive force, so during half of the oscillation, it simply releases the diaphragm and doesn't do any work. This mechanical inefficiency can be improved by replacing the string with a rigid arm that can both pull and push the diaphragm.

Figure 11: Rigid Arm Design



As shown **Figure 11**, the rigid arm consists of two members connecting the motor to the diaphragm. The pin joints and the roller supports help to convert the radial motion of the motor to the linear displacement of the diaphragm. The material for building the rigid arm hasn't been finalized yet, however, possibilities include clothes hangers, a car antenna, or other easily obtainable rigid materials.

As for the diaphragm, the original rubber balloon design was thin, weak and has deteriorated over time. This can easily be improved by using a different diaphragm material. Tire inner tube rubber is one of the best alternatives because it is thicker and therefore more stable and more durable. It is also widely available in a third world country setting. Building a new diaphragm out of inner tube materials will result in a more consistent and reliable vacuum generated over time.

Another possible way of improving the vacuum source is by replacing the original diaphragm with a syringe. The handle of the syringe would be attached to the motor by the rigid arm and the opening of the syringe would be indirectly attached to the two one-way valves via a splitter. This design would dramatically deviate from the original

vacuum source apparatus. One advantage of this method is that with the syringe, the amount of vacuum generated can easily be quantified and thus precisely controlled and varied. However, construction of this design will require significant mechanical expertise to control the force from the motor onto the syringe. If too much force is exerted, it can cause the syringe to break; if too little force is exerted, it can be insufficient to operate the syringe due to friction. Thus, because of the design constraint that the aspirator must be built with minimal expertise, it was decided that the rubber diaphragm will be used for the final design.

Improvement 2: The Check Valve Design

Another aspect of the previous aspirator design needing improvement was the check valve design. Two different valve designs were used in the previous design. The valve at the entrance of the vacuum chamber was taken from a bulb sphignomonometer. The valve at the exit of the vacuum chamber was constructed from the neck of a balloon which would collapse in on itself to block reverse airflow.

Although these valves were functional, they had two disadvantages. The primary disadvantage was that the sphignomonometer valve was impractically expensive; it required the purchase of an entire sphignomonometer to get only one valve. The second disadvantage was that the balloon valve was inconsistent. The balloon rubber was too flexible and wouldn't always form a seal. Thus, a valve design was needed that would be both inexpensive and efficient. After discussing different valve designs with Dr. John Webster, the following three valve designs were developed: the ball valve, the single-flap valve, and the double flap-valve.

The first design considered was the ball valve, which consists of a small ball (such as a marble or a ping pong ball) inside of a funnel, with either a rubber ring or a coating of grease acting as a seal between the funnel and the ball. In this design, the ball is lifted by outgoing air and then falls back into place, blocking reverse airflow. This design has several disadvantages. First, it can only function if the funnel is in an upright position, making it difficult to use for the entrance valve. Second, it is susceptible to failing if the aspirator is bumped or tipped while in use. Finally, it is difficult to form a tight seal between the ball and the funnel. When a rubber ring is used, it deforms slightly when attached to the funnel, allowing air around the ball. When grease is used, it slows the ball down, keeping it from falling back into place fast enough.

The second design considered was the double-flap valve consisting of two flaps of rubber held together over a rigid ring. It operates on the same principle as the previously used balloon valve; the flaps open to allow air through, and then collapse in upon each other to block reverse airflow. The difficulty with this design is that it is difficult to cut the pieces of rubber to the right shapes and sizes and attach them in the right orientation to get a tight seal. Thus, although this design is functional, preference was given to a simpler design.

The third and final design considered was the single-flap valve, which consists of a single piece of rubber glued to the top of a rigid ring to form a flap. The flap lifts to allow air to pass through, and then snaps back into place, blocking reverse airflow. If the rigid ring is glossy (like the lid of a metal food can), the valve readily forms a tight seal.

This single-flap was chosen as the final valve design because of its advantages over the other designs. It is much better than the ball valve design because it works

faster, doesn't need to be held upright to function, and it is less expensive. It also has two advantages over the two-flap valve. First, it is simpler to construct, which is important because it needs to be able to be constructed with limited expertise from a set of instructions. Second, it is smaller, allowing it to fit easily inside a pipe and thus be used for both the entrance and exit valves.

Improvement 3 :Hospital Integration

There are many things that need to be accomplished related to hospital integration before third world hospitals can implement the design. The first is an overall reduction in size. Currently, the design is too large to feasibly be used in a hospital or operating room setting. The overall length can be reduced by decreasing the distance between the diaphragm and fan motor with the proposed two-member, rigid arm design. Presently, a larger distance is needed to prevent wear on the string where it is fed through the syringe that refines the linear motion. The rigid arm design can be shorter, using the system of rollers to reduce the strain on the rigid arm member that only moves linearly. Wearing down of the rigid member will not be as much of an issue as the string breaking. Also, the overall size can be reduced by decreasing the size of the frame that supports the individual components. Arrangement and support of each component may need to be analyzed to determine what orientation will work best for the design. In the end, however, the design will not be as compact as current aspirator models due to a lack of technology and machining ability in the third world countries.

Another area that needs to be improved is safety. The current design has the wires, battery, fan motor, and diaphragm all exposed. All of these components should be covered. In addition to preventing injuries to people, the cover will be useful in

protecting the aspirator from damage. Any liquid spillage or mechanical damage could result in harm to both the aspirator and anyone in the room. A cardboard cover would be easy to shape, but not sturdy or easy to clean. A hard plastic cover would provide a good barrier between the inner workings of the aspirator and anyone using it. It would also be easy to sterilize.

The developing world hospital may only be able to afford one working aspirator. Therefore, it will probably be necessary to easily transport the aspirator from one room to another. A simple push cart would work, assuming the aspirator is small enough to fit. If this is not available, a specialized cart could be constructed to fit the aspirator components.

A simple aspect of the design that is missing is an on/off switch. Presently, the fan motor is turned on and off by manually attaching and removing the wires directly from the base of the motor. Not only is this approach slightly dangerous, the wires can be difficult to connect to the motor. A solution to the problem would be to insert an on/off switch into the circuitry. This switch could then be attached to the cover, allowing the user to easily turn the aspirator on and off without having to get near the motor or battery.

Finally, pressure regulation would be a useful application in the operating room. Depending on the procedure, the aspirator may need to slowly drain blood from the patient or it may need to rapidly suction large amounts of fluids. One way to accomplish this would be to insert a bleed valve in the tubing between the collection chamber and the inlet valve. Opening or closing the bleed valve would alter how much air is being pulled in by the diaphragm system, and in effect change the suction rate. Another way to alter

how much air is being pulled into the system would be to alter the rotational speed of the motor. Different resistances can be applied to the circuit to speed up or slow down how fast the motor rotates, thus altering how many times the diaphragm is pulled and compressed. Since the air flow depends on the displacement of the diaphragm, the amount of air pulled into and pushed out of the system will change depending on how fast the motor rotates.

Future Work

During the remainder of the semester, the improved aspirator must be built, tested and most importantly explained in a detailed set of instructions. The new design will include all of the optimized components described in this report. Flow rate and pressure will be tested over the maximum range possible. If the design is still not meeting specifications relative to those seen in current medical aspirators, further design refinement will be needed.

Finally, EWH requires an easy to read yet detailed set of instructions so that the device may be implemented in third world countries. The instructions to build the device will include the cost and possible source locations for each part used. EWH has specified that the instructions should be written for a high school educated audience. It is very likely however, that many who could benefit from this design are not fluent in English. Therefore, a detailed series of assembly pictures and diagrams will accompany the construction instructions. Similarly, the instructions for the testing and general use of the device will be written clearly and accompanied with several pictures and diagrams. Future time spent on this project will roughly be divided in half between

constructing/testing the improved prototype and writing the instructions for EWH. The more expensive components of the prototype will be reused from last year, so future costs should be minimal, not exceeding $20.

Conclusion

It is evident, as previously discussed, that the prototype developed last 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. By improving the vacuum source, check valves and hospital integration the overall device should be serve as a functional aspirator in a third world setting. With continued work, by the end of a the semester a functional prototype along with a complete set of instructions will be complete, which could benefit developing hospitals around the world.

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Appendix A - PDS

Product Design Specification (PDS)

Engineering World Health Aspirator (October 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 and develop a set of instructions for 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 12V batteries and/or manual 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:* Must provide safe regulated pressures within developing hospital environment.
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.