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 less power dependant alternative to current medical aspirators, that can be used by developing world hospitals.

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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 of 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 two. 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 (Allied Healthcare Products, Inc 2005). 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 ineffective 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 AC electric power. 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 in., 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. (Allied Healthcare Products, Inc 2005)

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 pipe 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 pipe **(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 pipe 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 pipe constriction generates a partial vacuum responsible for drawing fluids in through the autoclavable tip for deposit into the collection chamber.

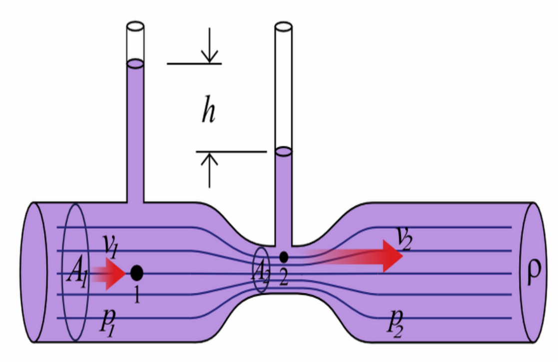

Figure 2: Venturi Pipe
As the velocity increases through the constriction, a partial vacuum is generated as shown by the altered height (h) of the liquid. Source: www.wikipedia.org

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 setup 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 suction 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 resume 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 tarnished. 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 an internal combustion engine **(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 pressure 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.

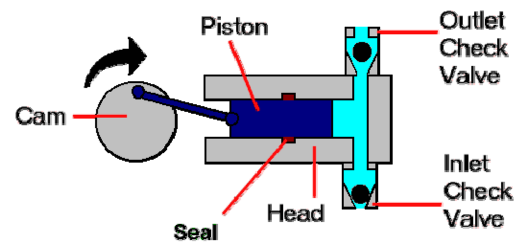

Figure 4: Internal Combustion Engine. Our system mimics these principles. Source: www.lcresources.com

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

Future Work

In the next few weeks, the final design choice of the electric pump will be improved by compensating for some of the flaws that appeared in the design matrix. After gathering materials needed for the prototype, it will be built, then repeatedly tested and modified.

An obvious disadvantage of the electric pump when compared with the foot pump and the water hourglass designs is that it is electricity dependent. Occasionally in third world hospitals, electricity supply will be shut down in response to a shortage of power. In order to perform medical procedures requiring suction of bodily fluids during power shortages, alternative ways to operate the electric pump will be pursued in the future design process. Perhaps a simple plunger will be sufficient to run the aspirator by creating two-direction airflow through two one-way valves. Although not as consistent as the vacuum generated by the electric motor, this alternative is adequate as a temporary backup for an emergency operation during power shortage. More optimistically, an airflow control adaptor that will create a consistent output of airflow with an inconsistent input of airflow will allow the plunger alternative to come close to substitute the full potential of the electric motor.

As soon as the design is finalized various websites, hospitals or even junkyards will be searched for affordable materials necessary to build a prototype. Many problems such as dimensions, amount of vacuum pressure generated, and the consistency of the vacuum pressure may be encountered and will require remedying. The final and most time consuming phase of the project will be testing the prototype and adjusting various details based on testing results.

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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.