Abdominal Cavity Loading Device

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Abstract
Since the year 2000, over 200,000 soldiers in the US Military have been diagnosed with Traumatic Brain Injury (TBI). In addition, 275,000 civilians are hospitalized for non-combat-related TBI related injuries, annually. TBI caused by direct blows to the head has been researched extensively. There is another vastly unexplored hypothesis, which suggests that a strong enough blow to the abdominal cavity could generate a pressure response within the circulatory system that would in turn cause a volumetric blood flow to the brain. In fact, this mechanism relies on the principles of fluid-structure interactions thorough venous system. The Boston Children’s Hospital research laboratories are interested in exploring this theory through experimentation on lab rats. To conduct this experimentation, a device to deliver a mechanical force to the abdominal cavity of a rat has been developed. The device utilizes a pneumatic piston to deliver the aforementioned mechanical force and is controlled digitally via Labview software. The pressure surge is also monitored digitally. The device is consistent and reusable, has the ability to vary pressure response, duration, and frequency, and is compatible with the laboratory rat models. Preliminary testing was conducted on a simulated rat model made of silicone, and showed that this design can generate a noticeable pressure differential inside the abdominal cavity.

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The Need for Project

Traumatic Brain Injury caused by direct blows to the abdomen, not blows to the head, is a vastly unexplored theory with little to no experimental data. Research on the causes of Traumatic Brain Injury (TBI) is largely focused on direct blows to the head. Recently, clinical data among veterans has suggested that high impact on the abdominal cavity from a blast or explosion could cause TBI, which may not become fully developed until much later in the subject’s life. This hypothesis is based on the large displacement in fluid, causing the intracranial venous pressure to spike high enough to cause permanent damage in the structure of the brain. The Rotenberg Laboratory in the Boston Children’s Hospital is interested in this hypothesis, and requires a device to deliver a blow to the abdominal cavity of a rat specimen to simulate this phenomenon.

The Design Project Objectives and Requirements

This device will apply a variable, consistent force within a specified time window to the abdomen of a laboratory rat. The impact will be powerful enough to generate a pressure response within the subject’s circulatory system to potentially induce traumatic brain damage.

Design Objectives

The objective of this project is to build a device that will deliver a sudden abdominal blow to rat specimens. This will test the hypothesis of TBI occurring as a result of sudden venous pressure increase due to an abdominally received blast, causing damage to blood vessels in the brain. This objective can be accomplished by either applying pressure to the abdominal cavity of the rat or directly to the blood vessels themselves. The device must allow variable pressures, durations, and frequencies. The effects delivered by the device must be repeatable. The device must be reusable and must be compatible with the research laboratory’s rat models.

Design Requirements

The device must not be complicated to use. To facilitate this, a clearly defined Labview program will control the device. The force range of the device is 2 – 20 N. The pulse duration must be 10 – 20 ms. The cycle time of the device must be no greater than 500 ms.
Design Concepts Considered

Three initial designs were considered that met the project needs. They were systematically eliminated as the design was optimized.

Inflatable Bag

This preliminary design incorporated the use of an air bag that can be wrapped around the body of the rat specimen. As air is pumped into the bag, it inflates and squeezes the abdomen of the rat. It employs mechanics similar to that of an air bag system found in motor vehicles. With this design, the pressure induced by the bag is not easily controlled. The bag is wrapped around the entire midsection of the specimen, which makes it difficult to prevent the application of pressure to unnecessary regions of the specimen’s body, and thus could easily cause more injuries than intended.

Pressure Transducer on Vein

This preliminary design required the rat specimen to undergo a surgical procedure. While the specimen is unconscious, transducers will be placed inside the abdominal cavity and on the brain to read and calculate venous pressure differences. A peristaltic pump will be placed directly onto the specimen’s vein to simulate a blow to the abdomen directly. Although this concept is the most direct way to create a pressure response within the specimen’s circulatory system, creating a pressure transducer small enough to be placed on a rat’s vein would be an expensive to undertaking. Additionally, since this design requires surgery, the procedure will be time consuming and difficult to perform.

Stepper Motor

The design of the stepper motor device requires a motor to raise a known weight on and arm and either to release or to drive the weight at a determined speed toward the abdominal cavity. The process would be similar to dropping a hammer onto the
specimen’s abdomen. This design is not robust enough to vary the pressure time, duration, and frequency.

Recommended Design Concept

A mechanical force will be applied to the abdominal cavity via a pneumatic piston that is suspended over the sedated rat specimen.

Design Description

Our device delivers an impact to the abdomen with the use of a pneumatic air piston. The rat will be positioned and secured to the base of the fixture with the use of straps. The fixture, made of T-slot aluminum, has the pneumatic air piston positioned vertically and will strike the rat abdomen from above. The piston position is adjustable to change the displacement of the impact.

The piston is actuated by a controlled flow of pressurized air. The system is designed to be compatible with a laboratory supply of pressurized air (~ 60 – 100 psi) and can be easily be supplied by a rented high pressure tank in the absence of an adequate supply. The air supply is connected to a mechanical regulator set to 60 psi (the maximum safe operating pressure of the electropneumatic parts of the system) to protect sensitive parts. The air flows from the mechanical regulator into an electropneumatic regulator. The electropneumatic regulator electronically controls the air pressure from this component forward to ultimately control the force the pneumatic piston will apply to the rat. The pressurized air flows from the electropneumatic regulator into a solenoid valve. The solenoid valve is a normally closed valve that can be opened in response to an electrical signal. When the solenoid valve is open, the pressurized air flows into the piston and extends the head into the abdomen of the rat.

The electropneumatic parts are connected to a DAQ and controlled by a Labview program. The program prompts the user for the desired piston force or pressure desired and sets the

Figure 4: Simplified final design; from top to bottom: hose connected to air source, electropneumatic regulator, solenoid valve, and pressure gauge (to monitor pressure into piston)
electropneumatic regulator accordingly. The program then prompts the user when to open the solenoid valve and extend the piston arm into the rat. The solenoid valve then closes and the arm retracts.

**Experimental Investigations**

In order to determine if mild TBI can be induced in a rat via an abdominal impact, testing would need to be done. It is necessary for a pressure increase inside of the abdominal cavity to create a volumetric blood surge to the brain. To determine if this can be done via an impact to the abdomen, two test fixtures were made. The first fixture was a coke bottle filled with water and silicon tubing filled with water running from bottom to cap. The silicon tubing was connected to a pressure transducer and the coke bottle was oriented horizontally. Weights were then dropped in the side of coke bottle and pressure spikes in the water inside of the silicon tubing were observed as a response.

The hard plastic shell of the coke bottle was not considered a realistic representation of a rat model, so a second test fixture was created. A thin walled silicone cylinder with rigid plastic end caps was created. The silicone was used to better represent the flexibility and elasticity of a rat abdomen. This cylinder was filled with water and the silicone tubing filled with water was run through the middle as seen in Figure 5. Again, weights were dropped on the silicone cylinder and a pressure increase was observed by the pressure transducer.

These two tests proved that an impact applied to a flexible, fluid- filled vessel can propagate pressure through other flexible vessels. This can be translated to the rat anatomy representing an impact to a saline filled rat abdomen will propagate a pressure wave into the venous tree.
Key Advantages of Recommended Concept

The system is designed to be simple. The pneumatics offers a simple way for the force applied and displacement to be changed, whereas other actuation methods only involve displacement. The control of the system will be simple and easy to transfer to the laboratory where it will be used. The design will be low cost and well within our budget. Due to the amount of time spent on proof of concept, the short lead-time of this design will allow for the group to finish in time for final presentations.

Financial Issues

Since this device is custom made for research at Boston Children’s Hospital, it will not be mass-produced. The total cost of the project is roughly $950. There has not been any financial issues that have stalled the project. The total cost of the device is about $800 with the Omega Electropneumatic Transducer being the most expensive piece at $285. The cost of research, which includes testing and calibration leading up to the building of the device adds another $100 to the running total. The design is ultimately for use in a laboratory setting for a single reason and will most likely not be produced on a large scale. Most of the costs are one-time costs for parts that will not need to be replaced except for maintenance and repair. The hospital might need to purchase a compressed air tank, rated to roughly 100 psi, to power the device, which will cost around $50.

Recommended Improvements

The device could be more versatile if there were a variety of different shaped heads created for the piston. It could also have a sleeker looking frame. A variety of heads for the piston should be created. Changing the area of deformation of the abdominal cavity would likely change the pressure differentials within the rat as well. The frame of the device, made from 80/20 aluminum, is moderately bulky, which could make the device difficult to store in a crowded research laboratory. More time could be spent on streamlining the frame of the device. Ultimately, the
testing of the device on mockups and actual rat experiments will provide the necessary feedback for improvements.