Internal Aortic Dissection Monitor

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Abstract

We introduce a novel method of a real time alert system to reduce the in-hospital mortality rate of aortic dissection. Aortic dissection is a severe emergency medical condition that can arise in people with any medical condition that results in the weakening of the arterial wall, especially patients with hypertension, aortic valve disease, or aortic aneurysm. Aortic dissection is the event where the inner layer of the aorta develops a tear, allowing blood to enter and separate the inner and middle layer [Cleveland Clinic, 2021]. In some cases this can lead to aortic rupture. After diagnosis and finding the location of a possible aortic dissection via dye test, hospital staff can place our device via catheter onto the site of risk of the dissection. The device will employ a strain gauge to record the change in diameter in the aorta, and will activate an alarm if the change of diameter of the aorta reaches a threshold consistent with aortic dissection. The device itself will consist of a strain gauge, a comparator, a 555 timer, and an alarm module. When the strain gauge is placed on the region of interest, the voltage of the gauge will correspond with the diameter of the aorta in the region. When the output voltage of the gauge drops below a certain point, a comparator circuit will output a signal voltage to the 555 timer, which sends constant signals to the alarm system so hospital staff can be alerted. The application and assistance of this device can reduce the risk of sudden death of aortic dissection patients.

Introduction

Aortic Dissection (AD) begins when a tear occurs in the inner layer of the aorta. Upon tearing, blood pumping through the aorta will surge through the tear, causing a separation between the inner and middle layer (causing a dissection) [Cleveland Clinic, 2021]. The aorta is one of the main blood vessels in the body, responsible for the delivery of oxygen-rich blood and nutrients to nearly every major organ. An aortic dissection will significantly affect the flow of blood to the rest of the body, and may even stop if the aorta ruptures completely. AD is often caused by high blood pressure, as well as a weakened or bulging arterial wall, otherwise known as an aortic aneurysm. Aneurysms themselves can take years to develop, but once an aortic dissection occurs the patient will be left in critical condition. This condition is serious and often deadly, especially in older patients. Once an AD occurs, blood flow to the rest of the body is severely affected, often causing death in hours. Currently, the mortality rate for this condition is about 30% in hospitals [Cleveland Clinic, 2021].

The diagnosis of aortic dissection, as well as determination of the location of the site of the dissection, is not straightforward. There are two main types of AD: Type A Aortic Dissection and Type B Aortic Dissection. In Type A, the dissection takes place proximal to the heart, which can be immediately life-threatening and requires emergency open chest surgery. A Type B dissection occurs in the descending aorta further from the heart towards the abdomen, and does not normally require emergency surgery to treat. In the three layers of the aorta (inner, middle, outer), a dissection occurs when the inner layer tears and blood spreads between the inner and middle layer. However, further damage can result in aortic rupture, a complete tear through all three layers of the aorta. 40% of patients die immediately from complete rupture.

Our device is an Aortic Dissection Monitor. The purpose of the device is to alert hospital staff of an impending or occurring aortic dissection in a patient, reducing the response time of the hospital and allowing for a quicker emergency surgery to save the patient. The device outlined in this paper will be placed at the location of the aneurysm and sound the alarm should AD occur. To use the device, the hospital can employ a dye test to locate the site of aortic aneurysm, which is the most likely site of aortic dissection. After locating the aneurysm from the dye test and CT scan, the hospital can place the device, allowing them to monitor data while the patient remains under observation.

Methods

For an aortic dissection, it is difficult to record and predict when the aortic walls will rupture. The recorded mortality rate of elective or emergency procedures is 1.5% and 2.6% respectively. These

procedures are preemptive or immediate responses to aortic dissections or ruptures. On the other hand, the mortality rate of emergency procedures is 11.7%. These procedures are for patients who have their ruptures outside of a hospital and need a response time to begin their procedure (Erbel). Given this, the best-case scenario to decrease the fatality rate of aortic dissection is to record when the aortic wall ruptures in a hospital setting to get the fastest response possible. The increase in mortality rate responds with the length of time before acting on the rupture. For our design, we wanted to develop a way to record the change in diameter and convert this change into an electrical signal to activate an alert. The first problem to design would be how to record the change in diameter that dismisses the change in aortic diameter due to blood flow. Using a strain gauge, we can detect a rupture in the aortic wall due to the internal pressure pushing through the rupture and creating a much larger diameter than that expected in the aorta during blood circulation. The strain gauge would be placed on the inside of the aorta where an aneurysm is located. Placement of the strain gauge would be possible through a catheter after the location is determined from a CT scan. This will give us a resistance based on the natural diameter and curvature of the aorta. With this given resistance, our external machine consists of an input and output buffer that is connected to a speaker. The speaker will emit an alarm when the voltage imputed into the comparator is below the threshold voltage. Our design will allow us to monitor the rapid change in the curvature of the aorta due to a change in diameter caused by an aortic rupture. For our calculation, we noted from research from Erbel that the diameter of an aorta is directly correlated with an increase in complications.

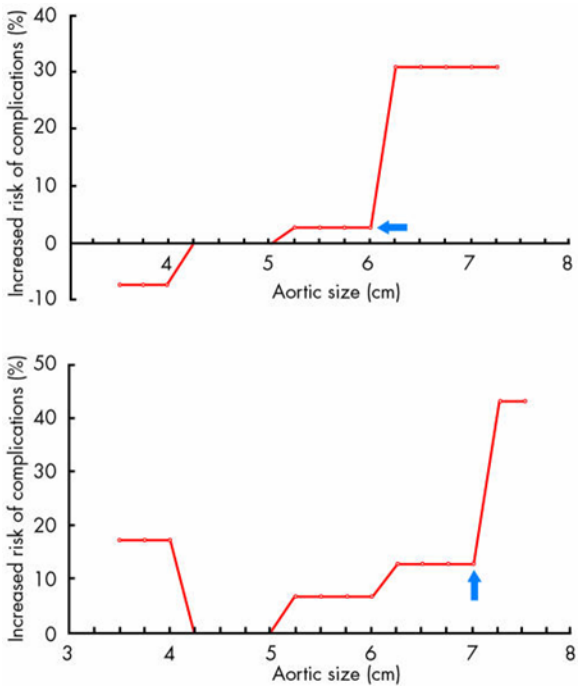

Figure 1: Graphs depicting the increase in the risk of complications during an aortic dissection repair based on the size of the ascending aorta (top) and the descending aorta (bottom) diameter size.

Using the figures above, we determined that we needed to record when the diameter recorded is above 6cm. while this may not be a direct sign of an aortic rupture, it could indicate signs of partial aortic dissection or generate an opportunity to allow patients to have elective surgery. Overall, this would help save lives by decreasing response time or by acting on the aneurysm before it fully ruptures. To prevent any electrical complication, the only component of our design that would be inside of the body would be the strain gauge with wires leading out of the body and away from the heart. This would allow us to connect the strain gauge to the rest of our design along with an external power source. In the rest of our circuit, we would be able to apply a voltage through a resistor and the strain gauge to record the voltage output under normal aortic diameters. We are then able to alert doctors and hospital staff when this voltage drops due to an aortic rupture.

Design

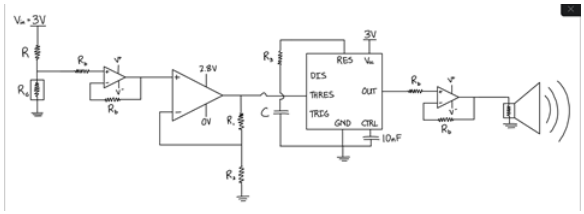

Figure 2: Aortic Dissection Alarm System.

Component:	Value:
R	100kΩ
$R_1 = R_2$	1kΩ
R_3	1MΩ
C	1μF
E	10kPa
G	1000
σ_{max}	0.055m

Table 1: The values used for a typical scenario of an aortic aneurysm.

The strain gauge is placed upon the region of interest, in this case upon the aneurysmal tissue of the aorta, or any artery suffering from an aneurysm at risk of a rupture. The expression for the voltage after the strain gauge can be computed by:

$$V_0 = V_{in}(R_G/(R + R_G)) \quad (1)$$

Where:

$$R_G = R(1 - \sigma/E * G)$$

We obtain a linear relationship of the strain gauges' reduction in length to its reduction in resistance, thus V_0 is expected to decrease across R_G as the aneurysm ruptures and reduces in size:

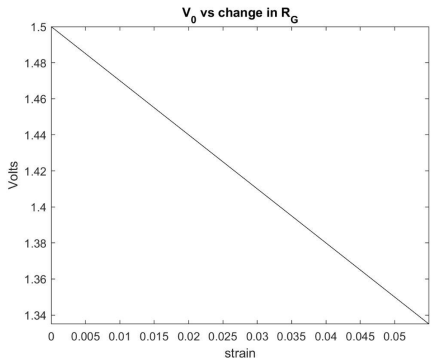

Figure 3: The trend curve for output voltage from the strain gauge with values from table 1.

Following this strain gauge is a comparator which operates by the conditions:

$$V_{+/-ref} = R_2/(R_1 + R_2) * V_{comp+/-} \quad (2)$$

By plugging in values from table 1 using equation (2), it is obtained that:

$$V_{-ref} = 1/2 * 0 = 0$$

$$V_{+ref} = 1/2 * 2.8V = 1.4V$$

Thus, if the input voltage is above 1.5, the output voltage will be a constant 1.4V, but if the voltage drops below 1.4V, the output voltage will drop to 0. This voltage behavior follows as shown below:

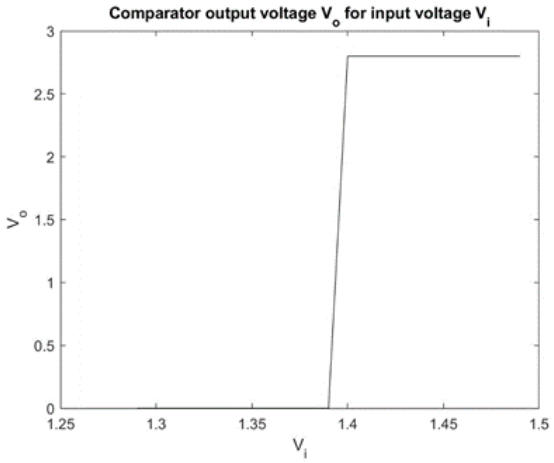

Figure 4: Graph of the voltage output from the comparator based on the input voltage.

This voltage is then carried into the input of the timer 555 trigger. Once the voltage reading hits 0 due to the reduction in strain gauge resistance, the timer 555 will output a signal of 2V constantly as this input trigger value continues to be 0. This output 2V from the timer 555 is connected to an alarm so that the patient can receive treatment for the ruptured aneurysm.

Conclusion

With the internal aortic dissection monitor, patients and healthcare professionals are able to get notified when an aortic aneurysm develops into a rupture or dissection which can become more fatal if not treated. A limitation of this device is its invasive nature due to the use of strain gauges. Since these

strain gauges would need to be placed at the site of the aneurysm on the walls of the aortic valve, it would require the use of a catheter to place the strain gauges. Since it is not practical to place strain gauges at every part of the aorta, another limitation is that the health care professionals would need to know the site of the aneurysm prior to placing the strain gauges. Therefore, they would need to perform a dye test to make the aneurysm more visually distinct when doing a CT scan to identify the location of the aneurysm. This device is also limited in its ability to detect the formation of an aneurysm or predict an aortic rupture/dissection before it happens since our device is triggered by the reduction in strain gauge resistance once the aorta ruptures.

Despite these current limitations, the application and assistance of this device could reduce the risk and rate of sudden death for patients who experience an aortic rupture or dissection. 40% of patients to die immediately from aortic ruptures and the internal bleeding out of the aorta, and the risk of death increases by 1 to 3 % per hour until treatment for the aortic rupture is treated [Cleveland Clinic, 2021]. Therefore, the aortic dissection monitor can reduce this statistic as health care professionals will know as soon as the aorta ruptures and can act quickly to treat it. The aortic walls are composed of 3 layers (intima [inner], media [middle], and adventitia [outer]) and make an aortic rupture and dissection distinct. For a dissection,it is the innermost, intima layer that ruptures and causes blood to flow between the layers which causes the aortic layers to further separate. On the other hand, an aortic rupture is the complete rupturing of all three layers of the aortic wall. With this, the design of our device can be improved with the addition of more strain gauges which can give it the capability to detect if either an aortic rupture or dissection happened. Placing a strain gauge at each layer and having a corresponding alarm would enable healthcare professionals and the patient to know which layer(s) are ruptured so that they can better determine the optimal treatment. Lastly, the current design is made to work within the hospital connected to an external power source and an external alarm. This being the case, a future application of this concept would be to make a portable version similar to blood glucose monitors. By doing this, a patient who has an aneurysm would have the strain gauges placed in their body through the use of a catheter and have the wires run through the body in a tube to prevent interference with the body and make the connection wires accessible outside the body. Then with a portable device that contains the power supply and alarm, the patient would be able to connect the device to their internal strain gauges and be notified if an aortic rupture or dissection happens. Ultimately, our device provides patients and healthcare professionals with the ability to get notified of an aortic rupture or dissection to improve the survival rate and give them important information that can assist in treatment methods.

References

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