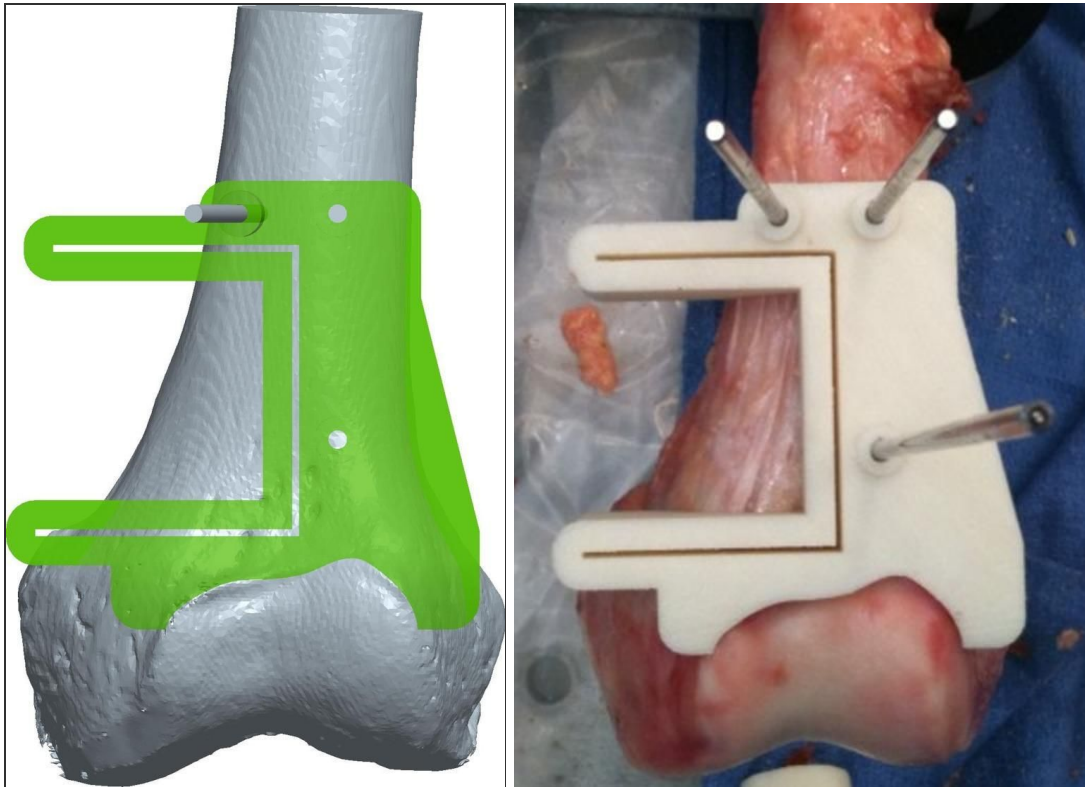


# 3D Printed Orthopedic Cutting Guides for Veterinary Surgery



**UW Madison Veterinary Feline Osteotomy Team**  
**Department of Mechanical Engineering**  
**University of Wisconsin - Madison**  
**4-29-18**

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## Executive Summary

Veterinary surgical procedures used to fix deformities in animal bones have traditionally relied on the surgeon's freehand cutting abilities. With the aid of 3D design software and CT imaging surgeons can now map out their surgeries quite accurately but the actual accuracy of the cuts is left entirely to the competence of the surgeon. Herein lies the motivation for our project. This report aims to present our attempt to collect data to determine the feasibility of using 3D printed cutting guides to increase the accuracy of surgical cuts.

Orthopedic cuts are generally quite complex for instance a cut may be oriented 23 degrees from the sagittal plane and 14 degrees from the frontal plane. Using a cutting guide the surgeon would be able to perform this cut with accuracy and precision. Ideally, this improved accuracy could provide an enhanced recovery both in the long-term and short-term. However, there is very little research on this subject that demonstrates the safety, and long-term effects cutting guides have on the health of the animal. Our research aims to quantify the safety of the cutting guide with wear and thermal tests, and determine the cutting guide's accuracy with metrology.

Our research in the first semester accomplished our goal of determining the safety of cutting guides for use in surgery. The main concerns with safety were heat and wear. Since, the cutting guides are made out of plastic, we hypothesized that the friction of the saw blade moving on the cutting guide surface could generate enough heat to deform the cutting guide. In our testing we found that no significant increase in temperature occurred on the cutting guide surface.

Our second concern regarding safety was wear. We were able to conduct wear testing parallel to heat testing and found very little material was lost during cutting. This means that our client can safely cut knowing that polymer material is not contaminating the wound of his patient.

This semester, we accomplished our goal of testing the accuracy provided by cutting guides. Our biggest concern with the accuracy of cutting guides was whether or not they significantly improve the accuracy of surgical cuts compared to freehand surgical cuts. As a result of testing, we found that 3D printed cutting guides can offer improved accuracy to cuts made on bone. However, a greater sample size is required to prove their viability.

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## Introduction

Deformities in the bones of animals can cause severe pain, infections, and can threaten the animal's ability to move on its own power. The surgical procedures required to fix these conditions require a very high level of accuracy and it is often left up to the skill of the surgeon's freehand cutting ability alone to achieve. The UW-Madison School of Veterinary Medicine performs around 160 of these types of procedures in a given year. This report will explain the procedure we took to investigate the feasibility of using 3D printed methods to create patient specific orthopedic cutting guides using UW-Madison resources.

While there are already examples of this kind of technology being utilized in both animals and humans, most of these cutting guides are created by 3rd party sources<sup>[2,4]</sup>. The problem with ordering a guide from an outside source is the cost, which in the case of animals, can often deter owners from having the procedure done on their pets.



**Figure 1:** Left) Example of a 3D printed cutting guide being tested on cadaverous human bone.<sup>[4]</sup> Right) Example of 3D printed cutting guide mounted on a 3D printed dog forearm.<sup>[2]</sup>

Figure 1 shows examples of existing 3D printed cutting guide concepts. While these guides exist, there still is not a large amount of data regarding their safety and overall efficiency. This prevents the guides from being used regularly in surgery. This report will outline the testing results from analyzing the safety and accuracy of 3D printed cutting guides. The safety testing will be concerned mainly with heat and wear of the material during the cutting operation. Heat could cause the material to melt and deform which could lead to inaccuracies. Wear can leave particulates of material in the patient which may cause any number of side effects. Accuracy is important as the goal of using cutting guides is to have better accuracy than a free hand cut.

## **Problem Statement**

Bone deformities in both animals and humans can often lead to future problems such as pain, infection, and loss of mobility. These issues can be exacerbated by a lack of surgical precision. Our client Jason Bleedorn, a surgeon within the UW Veterinary Department, is looking for a cost efficient way to fabricate an orthopedic cutting guide to aid the removal of bone deformities in animals. Currently, methods to obtain an accurate cutting guide can cost up to 10k, which normally is too expensive for an average pet owner. We hope to utilize 3D printing as a less expensive alternative to provide these guides to Jason Bleedorn and his colleagues and to increase the general quality of orthopedic care for animals over time.

## **Background**

### Bone Deformities

Bone deformations may occur during the congenital phase of life (birth), during the developmental phase, or may result from some traumatic event such as damage to the growth plate. In addition, the type of bone deformation varies. There can be an angulation deformity (bend in the bone), rotation or twist of the bone, displacement of the bone, or a length discrepancy<sup>[17]</sup>. Fixing these bone deformities requires a fine degree of accuracy by the surgeon, as well as adequate materials for surgery.

According to the Heidelberg bone correction surgery<sup>[6]</sup>, a three step process is used to fix a two stage bone deformity in humans, however this process can be mimicked on any animal bone as well. The procedure is as followed: the surgeon first identifies the CORA (Center of Rotation of Angulation) which is where the proximal and distal axis of the bone meet as shown in figure 2. Then, the surgeon uses a bone saw to move the bone and align its anatomical axis. The final step is to plate and screw the bone in the correct place using double locking screws. This allows for the proper healing and correction of the bone deformity. The process is very similar to that of Jason Bleedorn, a Veterinary Surgeon at the UW Veterinary Hospital.

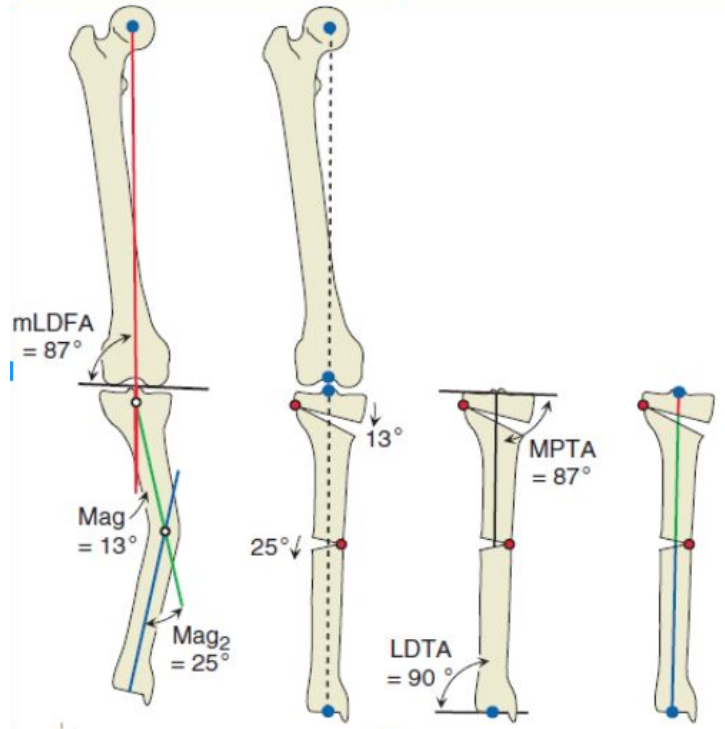


Figure 2: Bone Deformation Correctional Surgery. CORA(s) located at white dot.

### Existing Methods

There are currently third party companies that manufacture orthopedic cutting guides that can be used to assist the surgeon when making the bone cut. A process called Visionaire (Figure 3) was developed by a team of engineers at Smith and Nephew. It allows radiologists to take CT images and x-ray images of a patient's deformed bone, and create a specific cutting guide for that individual. However, this process is only used in human knee replacements and not for correcting bone deformities<sup>[9]</sup>. One key step in Visionaire's process is manufacturing the cutting guides. Currently, their main method of production is by using a CNC (computer numerically controlled) machine. This can be very time consuming and costly as there are many alternative approaches, namely 3D printing, that could be taken.



Figure 3: Visionaire Company



Figure 4: Stratasys 3D printing Company

In addition to a patient specific process such as Visionaire, there are more general cutting guides on the market. For example, there is a device produced by Johnson & Johnson in which

surgeons may attach different sized cutting slots on to a mechanism which allows a variety of different angles and sizes of cuts to be made<sup>[18]</sup>.

Stratasys is a 3D printing company and manufacturer of 3D printing materials (Figure 4)<sup>[8]</sup>. 3D printing technology is still relatively new having come out in the past few decades. It offers an incredibly intricate and promising solution to time consuming machining. This technology can be used to 3D print a cutting guide for a particular animal or patient. Using CT scans and the software CALYPSO, we will be able to send a geometric model to SolidWorks or 3-matic, which will then be uploaded to a 3D printer.

### Marketability

Veterinary surgeons would primarily benefit from having a patient specific orthopedic cutting guide, as it would allow for a much more accurate and precise cut when correcting the bone. By importing an image of the bone geometry and using 3D printing technology, the cutting guide will be able to fit snugly with little or no human error. The guide would also help the animal with recovery time, as a more precise and efficient surgery will allow the bone to heal more quickly. Finally, the animal owners in turn will have more trust in the surgeon if proper instruments are used in surgery. Overall, the cost of transitioning into a more patient specific approach to correcting bone deformities is unknown currently, as there hasn't been enough research on the topic; with that said, the opportunity cost of the surgeon will go down because of a quicker surgery.

## **Objectives**

The aim of this project is to collect data and determine the feasibility of 3D printed cutting guides using resources within the University of Wisconsin-Madison. The two main areas of interest are safety and accuracy. The first semester of this experiment was focused on analyzing the safety aspect of this research. The second semester was focused on doing accuracy testing with two different types of guides.

### Biocompatibility

With any cutting process there will always be material lost in the form of dust particulates. In our case, there will be dust from the bone being cut and potentially from the cutting guide itself depending on the toughness of the material. If there are particulates coming off of the guide we must determine how much is being lost and what are the acceptable levels of that specific material getting into a surgical wound, if there are any.

### Accuracy

A major goal of this research is to provide surgeons with a way to increase the accuracy of their cuts. For this we created an optimal testing environment and guides for two different

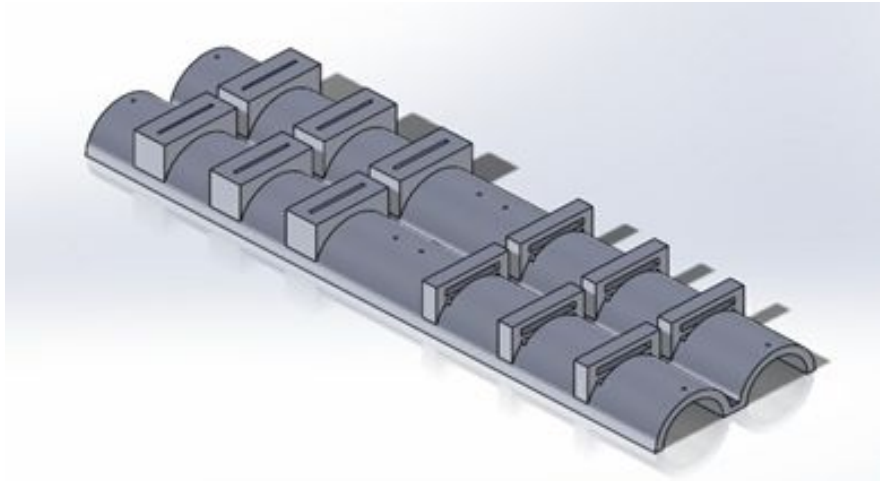


geometries. The first geometry was a machined PVC pipe and the second was a 3D printed bone given to us by our client. The goal was to quantify how much a guide would change the angularity of a cut in different shapes, and to compare this against a tolerance for cutting.

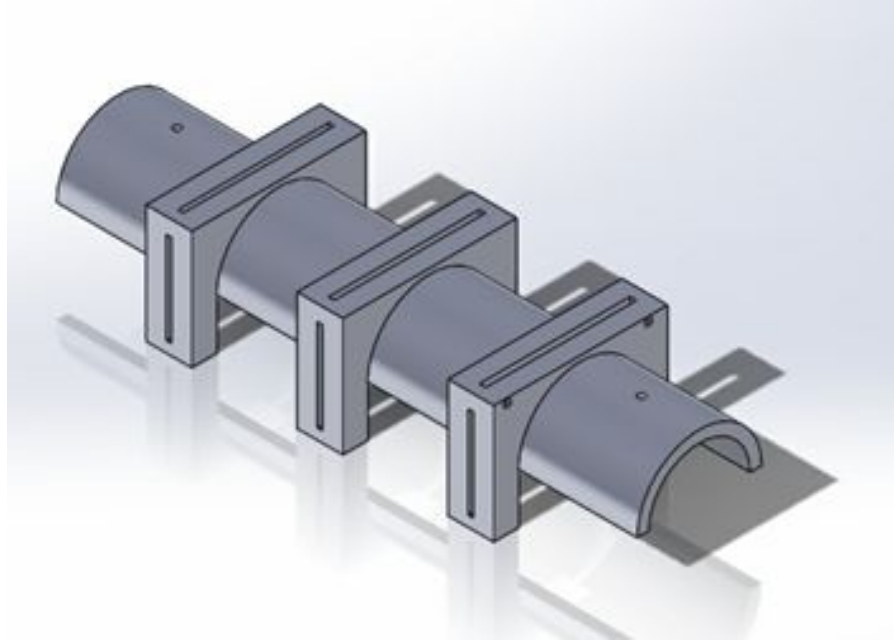
## Testing Guide Designs

### Preliminary Designs

We began by creating a few different testing specimen geometries, with varying gap widths, to be attached to bone analog substitutes provided by Dr. Bleedorn. These widths were varied by 0.05" starting at 0.15" greater than the blade thickness. Figure 5 shows our first testing specimen. It is designed such that there are only two wear surfaces during cutting to reduce heat by friction. It also has holes at each end of the guide to help mount it to the test piece as well as holes in the front faces of the guides to allow for temperature probes to be embedded in the guide.



**Figure 5:** The first cutting guide test specimen with one and two sided guide concepts. The part is arranged such that we could maximize the number of guides we can achieve with one 3D print.



**Figure 6:** 3D model of another iteration of the test guide. Slotted sides allow debris to be naturally removed from the guide during the cutting process.

### Current Design

The final design of the test guide was intended to test angled cuts that would be closer to what a surgeon would do in a real surgery. The guide we came up with includes a 30° angle in the frontal plane and a 30° tilt in the sagittal or side plane.



**Figure 7:** 3D model of the current test specimen which includes compound angles to simulate actual surgical cuts.

## Testing

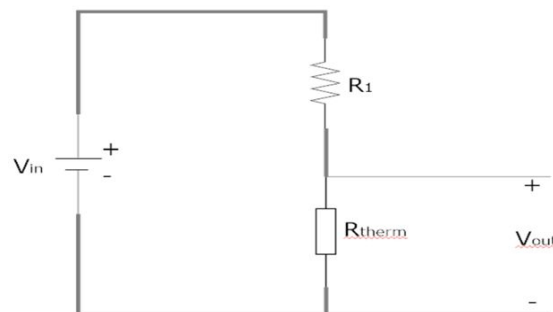
### Weight

This test quantifies the amount of material lost in the cutting process. The testing process is as follows:

1. Weigh the part before cutting.
2. Carry out a cutting test.
3. Weigh the part post-cut.
4. Compare before and after.

### Heat

The thermal analysis involves using thermistors embedded in the test guide which actively measures the wear surface temperature during a cut. We wish to measure this because if the guide becomes too hot during testing it could deform the guide leading to inaccuracies in cutting. The thermistors will be set up in a voltage divider circuit with a known resistance, as seen in figure 7, and connected to a data acquisition system (DAQ).



**Figure 8:** Voltage divider circuit used to determine temperature.

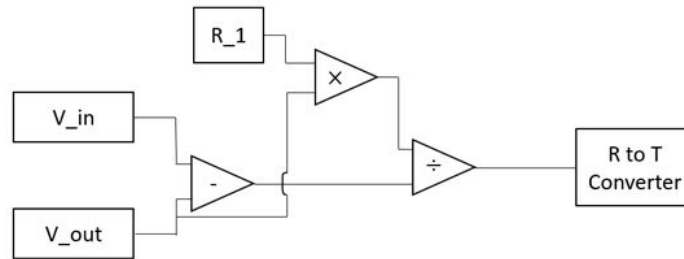
The DAQ will read the voltage of the thermistor ( $V_{out}$ ) and the input voltage ( $V_{in}$ ) into LabVIEW to determine the instantaneous resistance of the thermistor, shown in figure 8. Thermistor resistance is calculated by:

$$R_{therm} = \frac{R_{known} * v_{out}}{v_{in} - v_{out}} \quad (1)$$

For our testing, we used NTC thermistors which had a pre-defined curve relating resistance to temperature. This curve was calculated using the equation:

$$T = \frac{B}{\ln(\frac{R}{r_{\infty}})} \quad (2)$$

Equation 2 was then input into the LabVIEW VI (Appendix B) to obtain a continuous temperature read-out.



**Figure 9:** Block diagram representing the calculations being done within LabVIEW. The full VI can be found in the Appendix.

### Accuracy

Accuracy analysis is meant to determine the degree of improvement seen by cuts made with the use of a cutting guide versus cuts made freehanded. This is done by attempting to cut a test piece at a 30° angle in the frontal plane and 15° angle in the sagittal plane first with a guide, then without one and comparing the two. Unlike the previous tests, accuracy testing has two phases. These two phases include the use of different test pieces and guides, however their basic principle remains the same.

In the first phase, cuts are practiced on a standardized testing jig. The jig itself is a 6in PVC pipe with a milled 3in flat which a guide can be pinned on. For increased stability, the PVC is first bolted to a table. The guide can then be pinned onto its surface. For each cut made using the guide, another must be made freehanded, both attempting to cut at the same angle.

The second phase is very similar to the first. However, instead of cutting on a PVC test piece, the cuts are made on a 3D printed dog bone. This test uses a new guide made to fit the specific geometry of the area which it will cut. The testing is then carried out in the same way as in the first phase.

After all cuts have been made, the test pieces are scanned into the micro CT and imported into volumetric software where the angles on the cuts can be measured. This is accomplished by setting reference points on the test piece and then measuring the angles of the cut with a 3-point angle tool.

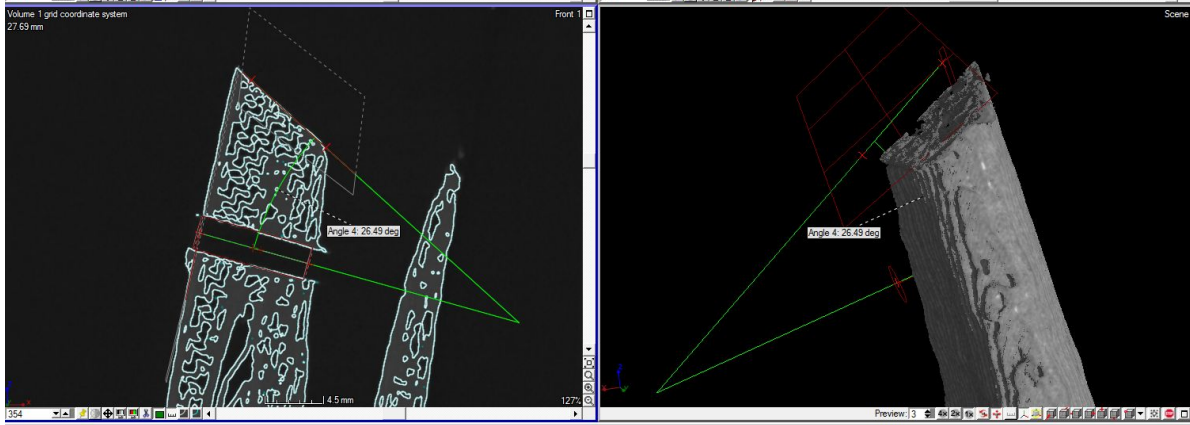


Figure 10: Measurement of angles produced by a guided cut via volumetric software

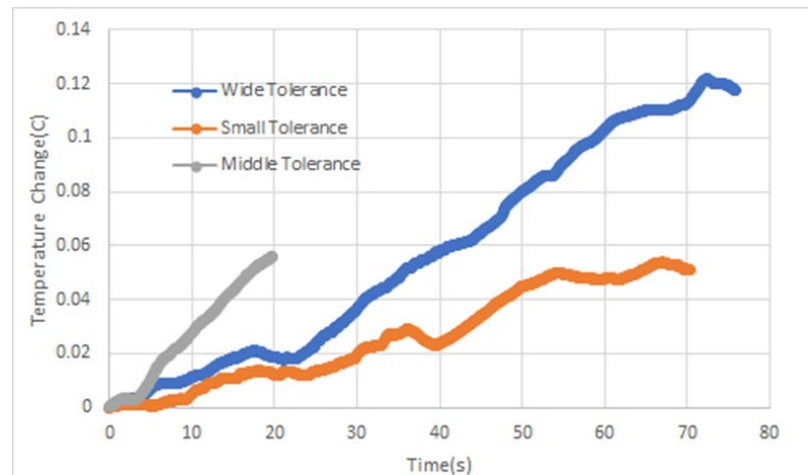
## Results

The weight measurement results were not what we expected because it showed a 3% weight loss. We suspect that this data may be flawed. Volumetric losses will need to be examined further with the CALYPSO software in the future.

Table 1: Weight Analysis Summary

	Before Cutting	After Cutting
Weight (mg)	21027.4	20379.8
Weight difference (mg)	647.6	
Weight loss percent (%)	3%	

Heat testing showed that there was no significant increase in the temperature of the wear surface of the cutting guide during cutting (Figure 9). From the data it is clear that cutting does not affect the material in any way as the temperature increases were on the order of  $\sim 0.1^{\circ}\text{C}$ .



**Figure 9:** Graph of the temperature change of the cutting guide vs cutting time.

Table 2 shows the results of our accuracy analysis. We measured the angles in the frontal and sagittal planes using either a volumetric CT software or an image based angle measurement program. We can see from these results that the cuts that use a guide on a 3D printed bone reduce the accuracy tolerance by about 2-3 degrees in either plane. The accuracies were actually worse using a guide on the PVC pipe.

**Table 2:** Average results of accuracy testing

	Target Cut	Free Hand	Tolerance (%)	Target Cut	Guide	Tolerance (%)
Testing Jig	30	27.01	2.99	30	34.35	4.35
	15	13.24	1.76	30	27.95	2.05
	<b>Total</b>		<b>2.375</b>			<b>6.40</b>
Printed Bone	30	33.44	3.44	30	29.30	0.70
	15	17.31	2.31	15	15.10	0.10
	<b>Total</b>		<b>2.875</b>			<b>0.80</b>

## Conclusions

It is clear from the work done this semester that more cut tests and measurements need to be taken in order for any findings to be statistically valid. We have, however, created a workflow for designing and 3D printing a cutting guide that can be custom made to fit any animal bone and can be CT scanned using university resources. This workflow can be used by any who wish to continue research on this process.

The results from heat testing are unreliable due to the discovery of a malfunctioning saw well after the data was taken, it would be necessary to redo the thermal testing. We are confident that there should be minimal problems coming from heat generation. For the same reason it may be useful to replicate the wear testing as well to see if there is more debris than initially measured.

The results of our accuracy testing were very promising. When testing a cutting guide on a 3D print of an actual bone we were able to achieve accuracies within 1 degree in both planes where the freehand accuracies were closer to 3-4 degrees in either plane. The reasons for why the cuts done on PVC with a guide were less accurate than a freehand cut are unknown, because of this further testing will need to be done to ensure statistical validity.

## Future Work

Every guide tested over the course of this project was printed in ABS. Had more time been available for this project, testing would have included guides produced with other materials. For example, heat and wear testing would have been conducted on guides made of materials such as PLA or acrylate. The results of these tests would then determine the best material to be used for 3D printed cutting guides.

Another test which would have been helpful had we been given more time, is secondary heat testing. In the previous semester, we measured the amount of heat transferred to the cutting guide and found it to be not significant enough to deform the guide. However, after these tests concluded, Dr. Jason Bleedorn suggested that the heat created by sawing may have been transferred to the bone instead of the guide. By measuring the heat transferred to the bone, it could be determined if the use of a guide is a safety hazard to the animal.

## **Methods**

### Hardware

The digital analysis of this experiment was possible thanks to the use of a Metrotom OS machine. This allows for the generation of a CAD image from a physical object.

### Software

During this experiment different softwares were used to manipulate and analyze the data obtained from the Metrotom OS, and to create the guides. Solidworks or any CAD software can be used to create simple 3D figures, but for actual bone applications it is recommended to use Materialize 3-matic. This software can be used to create custom guides on actual bone pieces.

### Printer properties

For this experiment a Stratasys dimension SST 1200 ES was used to 3D print all of the pieces. The material used to print was the ABSplus thermoplastic with soluble support materials SR-30 and P400 - SR. It is suggested to use a printer with similar characteristics for future research as during the experiment, the quality of the Stratasys prints were visually compared to that of a printer of lower quality (no details of the printer were gathered). The precision of print of the Stratasys was noticeable even to the human eye which suggests that a lower quality printer could not effectively help further analysis.

### 3D-Prints

For future 3D analysis, it is recommended to create physical landmarks to ease analysis. Having a landmark serve as a reference datum will help analysis by making it easy to measure angles and dimensions from the landmark to the cut being analyzed.

## **Appendix**

### A. Equations

Thermistor resistance in voltage divider (1):

$$R_{therm} = \frac{R_{known} * v_{out}}{v_{in} - v_{out}}$$

Where  $v_{in}$  and  $v_{out}$  are measured directly from the circuit via a portable DAQ.

□-parameter Equation (2):

$$T = \frac{B}{\ln\left(\frac{R}{R_0}\right)}$$

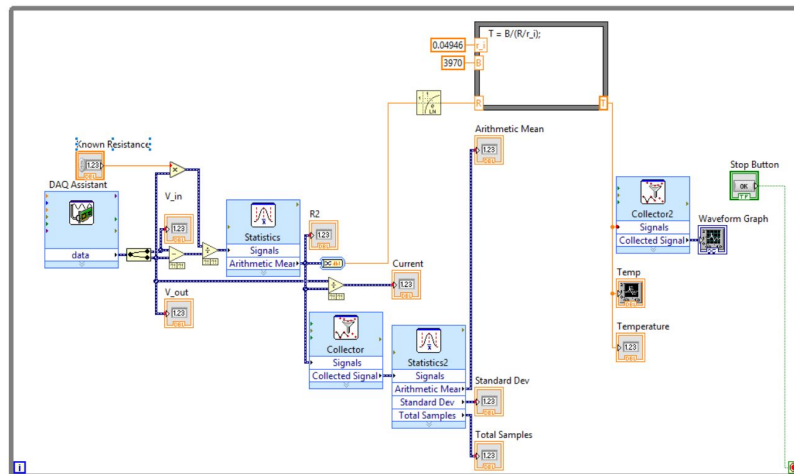
$$R_{\infty} = R_0 e^{-\frac{B}{T_0}}$$

This function is used to convert the resistance measured via Equation 1 into a readable temperature. The constants of the equation were determined from the provided datasheet which came with the thermistors.

B is the  $\beta$ -parameter, a given constant unique to the thermistor;  $T_0$  is the reference temperature; and  $R_0$  is the resistance value at that temperature. Their values are as follows:  $T_0 = 298.15$  K,  $R_0 = 30,000 \Omega$ , and  $B = 3970$ .

## B. Code

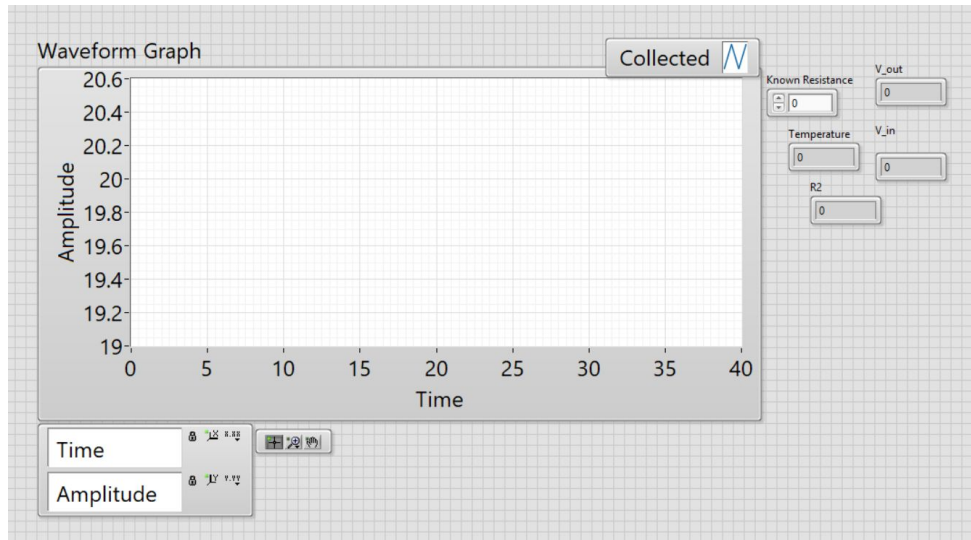
Thermistor VI Block Diagram:



Once started, the LabVIEW VI takes continuous data from the DAQ consisting of  $V_{in}$  and  $V_{out}$ . From these values, the resistance of the thermistor is calculated. The standard deviation and sample number of this resistance are calculated throughout the test duration. At the same time, thermistor resistance is converted into a temperature via the □-parameter equation (Appendix A). This temperature is then recorded and graphed. This cycle continues until the stop button is pressed.



### Thermistor VI Front Panel:



The front panel of the VI contains the temperature and circuit information as well as a continuous graph of temperature over time. The known resistance value used in calculations can be changed on the right of the graph. This allows the VI to work with different resistor values.

### C. Gantt Charts

Fall Semester:

Schedule for first semester of project		October				November					December			
		5	12	19	26	2	9	16	23	30	7	14	21	28
Meetings	Team	X	X	X	X	X	X	X	X	X	X	X		
Meetings	Faculty Adviser	X	X	X	X	X	X	X	X	X	X	X		
Meetings	Client					X		X		X				
Meetings	CT scanner training				X									
Deliverables	Final Progress Report											X		
Deliverables	Progress Report	X	X		X	X	X	X	X	X	X	X	X	
Deliverables	Fall Design Review				X							X		
Deliverables	Symposium Registration/Event											X		
R&D	General Research	X	X	X	X	X	X							
R&D	Testing proposal (faculty adviser)			X	X									
R&D	Testing									X	X	X		
R&D	Analysis									X	X			

Phase 1 End	Deliver recommendations/plan for next semester											X	X		
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Spring Semester:

Schedule for second semester of project		February				March					April			
		5	12	19	26	2	9	16	23	30	7	14	21	28
Meetings	Team	X	X	X	X	X	X	X	X	X	X	X	X	
Meetings	Faculty Adviser	X	X	X	X		X					X		
Meetings	Client	X				X						X		
Deliverables	Final Progress Report													
Deliverables	Progress Report	X	X		X	X		X			X	X		
Deliverables	Individual Presentations				X									
Deliverables	Symposium Registration/Event							X						
R&D	Calypso training			X										
R&D	Testing					X								
R&D	Analysis											X	X	X
R&D	Fabrication								X	X				

**D. PDS**

**3D Printed Orthopedic Cutting Guide**

Team Members: Andrew Knoepfel, Anuar Acosta, Chelsie Metz, Daniel Simmons, Thomas Friesch

**Function:**

Bone deformities in both animals and humans can often lead to future problems such as pain, infection, and loss of mobility. These issues can be exacerbated by a lack of surgical precision. Our client Jason Bleedorn, a surgeon within the UW Veterinary Department, is looking for a cost efficient way to fabricate an orthopedic cutting guide to aid the removal of bone deformities in animals. Currently, methods to obtain an accurate cutting guide can cost up to 10k, which normally is too expensive for an average pet owner. We hope to utilize 3D printing as a less expensive alternative to provide these guides to Jason Bleedorn and his colleagues and to increase the general quality of orthopedic care for animals over time.

**Client Requirements:** The cutting guide will be created using a pre-made CAD model specifying the specific dimensions of the specific animal bone, and we will be downloading the

CAD models to a 3D printer. The client will only need a few before the end of the semester, as Jason only has a couple bone deformation surgeries scheduled.

**Design Requirements:** The following list is a set of requirements that must be fulfilled by the final product.

## 1. Physical and Operational Characteristics

1.0 *Performance requirements:* The cutting guide must be used once for each specific animal surgery. It must be able to withstand high amounts of heat and pressure from the sterilization process, as well as heat and physical stress from when the saw blade moves along its edge. Most importantly this product must be produced in a more cost efficient way than the normal manufacturing process.

2.0 *Safety:* This product will be made of a polymer so it can withstand high temperature and stress. The product must be sterilized before use in a surgical setting and the manufacturing process must be user friendly and non hazardous. Any mixing of polymers or handling of the 3D printer should be done with caution.

3.0 *Accuracy, Quality and Reliability:* The manufacturing process must reduce the cost of production by 30%. This process must be repeatable in a timely fashion to ensure maximum manufacturing efficiency.

4.0 *Life in Service:* This process will be implemented and used indefinitely if it turns out to be more efficient than the current cutting guide manufacturing process. The guide itself will be used once on each specific patient case and then recycled.

5.0 *Shelf Life:* The process does not have a shelf life however the cutting guides will maintain their appearance and performance for long periods of time, as plastic is not easily corrodible.

6.0 *Operating Environment:* The process must be operable in any location with access to a 3D printer, electricity, and the correct polymer. The guide itself must be operable in a surgical setting. The guide must be able to withstand exposure to light, bodily fluids, metal, radiation from imaging, and physical stress. The guide must also be able to withstand the 121°C and 15 psi used in the sterilization process.

7.0 *Ergonomics:* The process is mainly computer operated. A CAD application must be accessible to create the design, and a human must import the CAD model to the 3-D printer. The

cutting guide itself must be user friendly and easy to handle for the surgeon and any surgeon assistants in the operating room.

8.0 *Size*: The manufacturing process is to ideally be large scale if it is economically efficient. The cutting guide's size will vary based on the specific case, however it must be large enough to allow for an accurate cut o the animal bone

9.0 *Weight*: The process does not have a weight, however the cutting guide's weight should be light enough to be easily handled, and durable enough to withstand force.

10.0 *Materials*: The process is to be made using CAD models, a 3-D printer, and a polymer.

11.0 *Aesthetics, Appearance, and Finish*: The produced cutting guide is to be smooth and precise.

## **2. Production Characteristics**

12.0 *Quantity*: The number of units needed during this process is one per surgical case. However, this production method will take place at a large scale.

13.0 *Target Product Cost*: The production cost of this method is to be 30% less than the standard manufacturing method.

14. *Testing*: We will test the different polymers in order to determine which is the best to use under the given stresses. We will then conduct a feasibility test in order to determine how much more efficient a 3-D printed cutting guide is compared to the normal CNC manufacturing method.

## **3. Miscellaneous**

15.0 *Standards and Specifications*: Cutting guides produced via this method must meet FDA regulations for use in a surgical setting.

16.0 *Customer Requirements*: This production method must be cheaper, faster, and more precise than the traditional method.

17.0 *Competition*: The current method of producing cutting guides is to mill them using CNC.

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