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ENGINEERING

100 Percent Report
Expandable Spinal cage

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This report is written in partial fulfillment of the requirements in EML 4511. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.
Ethics Statements and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Christopher Dominguez, Justin Crisp, and Peter Medrano and it is original. Excerpts from others’ work have been clearly identified, their work acknowledged within the text, and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development, and testing reported in this document are also original and prepared by the same team of students.

<table>
<thead>
<tr>
<th>Justin Crisp</th>
<th>Christopher Dominguez</th>
<th>Peter Medrano</th>
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</table>

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# Table of Contents

Abstract ................................................................................................................................. 1

1. Introduction ...................................................................................................................... 2
   1.1 Problem Statement ....................................................................................................... 2
   1.2 Motivation .................................................................................................................. 4
   1.3 Literature Survey ......................................................................................................... 5
      1.3.1 Overview ............................................................................................................ 5
      1.3.2 History ............................................................................................................... 6

2. Project Formulation .......................................................................................................... 11
   2.1 Overview .................................................................................................................... 11
   2.2 Project Objective ....................................................................................................... 11
   2.3 Design Specifications ............................................................................................... 12
   2.4 Constraints ............................................................................................................... 13

3. Design Alternatives .......................................................................................................... 20
   3.1 Overview of Conceptual Design ................................................................................ 20
   3.2 Design Alternative 1 ............................................................................................... 21
   3.3 Design Alternative 2 ............................................................................................... 22
   3.4 Design Alternative 3 ............................................................................................... 24
   3.5 Design Alternative 4 ............................................................................................... 26
   3.6 Feasibility Assessment ............................................................................................. 31
   3.7 Proposed Design ....................................................................................................... 31
   3.8 Discussion of Proposed Design ................................................................................ 32

4. Project Management .......................................................................................................... 34
   4.1 Overview .................................................................................................................... 34
   4.2 Breakdown of responsibilities .................................................................................. 34
   4.3 Time allocation breakdown ....................................................................................... 34
   4.4 Gantt chart Timeline .................................................................................................. 35

5. Engineering Design and Analysis .................................................................................... 36
   5.1 Structural Design ...................................................................................................... 36
      5.1.1 Extender Analysis .............................................................................................. 36
      5.1.2 Plate Analysis ..................................................................................................... 38
Figure 1: Anterolateral Depuy Expandable Cage Pack (Depuy) ................................................................. 3
Figure 2: Catalog for Expandable Spine Cage (Ulrich Medical USA) .......................................................... 3
Figure 3: Herniated Disk with Pinched Nerve (MayoClinic) ........................................................................ 6
Figure 4: Vertebral Compression Fracture (Jointandspinesurgery.com) ......................................................... 7
Figure 5: Example of one bone grafting approach (MayoClinic) .................................................................. 8
Figure 6: Bone graft from Pelvis (James Disability Law ) ........................................................................... 8
Figure 7: Charité artificial disc (MayoClinic) .............................................................................................. 9
Figure 8: Front and side view of Charité artificial disc (MayoClinic) ......................................................... 10
Figure 9: Human Spine Anatomy (Backpain-guide.com) ............................................................................. 14
Figure 10: Abbreviations for Vertebral Body Heights (Busscher, 2010) ...................................................... 15
Figure 11: References to Dimension Measurements (Kolta, 2011) ............................................................... 17
Figure 12: Alternate Design 1 ..................................................................................................................... 21
Figure 13: Alternate Design 2 ..................................................................................................................... 22
Figure 14: Alternate Design 3 ..................................................................................................................... 24
Figure 15: Alternate Design 4 ..................................................................................................................... 26
Figure 16: Alternate Design 4 Base Cylinder ............................................................................................. 27
Figure 17: Design Alternate 4 Screwing Mechanism ................................................................................. 28
Figure 18: Alternate Design 4 Locking Key ................................................................................................. 29
Figure 19: Alternate Design Middle Cylinder ........................................................................................... 30
Figure 20: Alternate Design 4 Top Cylinder ............................................................................................... 30
Figure 21: Proposed Design ...................................................................................................................... 32
Figure 22: Expander von Misses Analysis .................................................................................................. 37
Figure 23: Expander Factor of Safety Analysis ......................................................................................... 37
Figure 24: Plate von Mises Stess and Factor of Safety Analysis .................................................................. 38
Figure 25: Base Displacement Analysis .................................................................................................. 39
Figure 26: Prototype Final Assembly ....................................................................................................... 49
Figure 27 Frozen cadaver undergoing stress testing (Aghayeva, 2013) ....................................................... 52
Figure 28 Single level Assembly .............................................................................................................. 55
Figure 29: Double level assembly ............................................................................................................ 56
Figure 30 : Assembly - Step 1 .................................................................................................................. 56
Figure 31: Assembly - Step 2 ................................................................................................................... 57
Figure 32: Assembly- Step 3 ..................................................................................................................... 57
Figure 33 : Assembly - Step 4 .................................................................................................................. 58
Figure 34: Assembly - Step 5 ................................................................................................................... 58
Figure 35: Base 2 ....................................................................................................................................... 59
Figure 36: Spinning Ring ............................................................................................................................ 59
Figure 37: Contact Plate ............................................................................................................................. 60
Figure 38: Middle sized contact plate ...................................................................................................... 60
Figure 39: Base rod and extension .......................................................................................................... 61
Figure 40: Hollow middle screw rod ......................................................................................................... 61
Abstract

Spinal cages are fairly new in the medical world and are increasing in popularity as a method to cure several types of spinal conditions. Cages are being used as an aid in a surgical procedure known as spinal fusion. Fusion of the spine has been around for nearly a century and it is the surgical technique of joining two or more vertebrae together in both humans and animals. This method was first introduced to cure problems such as scoliosis and kyphosis of the spine. As an increase of back problems arose in the span of the century, so did the demand for new technologies to help the victims of these spinal conditions. According to the American Chiropractic Association, an estimated 31 million Americans suffer from back problems today. The ACA predicts that up to eighty percent of the population will experience back problem at one point in their lives. Some of those conditions may be treated with pain killers and physical therapy. For more severe conditions, an alternative solution must be found to help people who experience pain that is too much bare.
1. Introduction

1.1 Problem Statement

A wide variety of spinal cages are used today in the medical world for the use of spinal fusion corpectomies. The market is currently flushed with similar designs that help restore the spinal column. Although studies show these devices prove to be effective for the function they perform, there is a drawback to the similar approach in designs used for patients.

The human spine is made up 24 connecting articulating vertebrae separated by vertebral disks, along with 9 fused at the sacrum and coccyx, which will not be considered for this project. Starting from the lower skull flowing down to the lower back, each vertebra increases in size the lower they lie on the vertebral column. The varying sizes of the spine segments call for different size replacements to fit the vertebra undergoing the procedure. Since every human being has a similar but also unique bone structure, the implants must be precise in sizing to avoid any complication once the cage is permanently installed.

Many designs on the market today have made their vertebral body replacements adjustable by using an expanding mechanism to provide a solution to the varying sizes in the spine. By doing this, not only are the implants more precise to custom fit the patient but also drives down cost of manufacturing and material of the quantity produced. Still, it is not uncommon to see various spinal cages in the operating room throughout the procedure. A few examples below show one expandable spine cage system and the various sizes that are sold in a single pack and a separate system’s catalog for their implant.
After researching the procedure, a recurring theme of double digit cages in the operating room can be noticed. This is an inefficient method for cost reasons and allows for
errors to be more present because of the numerous options a surgeon has to choose from. Though the expandable cage in general does decrease the overall options for the procedure compared to non-expandable cages, the idea of having such wide variety of expandable cages is counter intuitive to one of the main reasons the expandable spinal cage exists.

Another drawback with current designs of expandable cages is the limitation in adjustability some encounter. Referring back to Figure 2, the catalog shown displays the expansion ranges for some common vertebral body replacements. Most expandable spinal cages can only double their size from the fully closed position and offer minimal solutions other than to purchase multiple implants to get the desired fit.

These two major observations regarding vertebral body replacements prove to be more costly for the patient since they are required to pay for the kit of implants not used. If a solution of a “one size fits all” expandable cage would be introduced on the market, the procedure would not only provide a more affordable implant, but also a more precise one.

1.2 Motivation

Living in today's world we are surrounded by many levels of advancements in technology and as engineers, it is our job is to seek solutions to the problems facing society today by looking for new innovative ways to help people. With millions of people suffering from back problems in America and around the world, our team has taken the initiative by utilizing what we have learned from our mechanical engineering education and applying it to a medical
aspect. Our new approach to designing an expandable spine cage will hopefully offer a fresh perspective to traditional spinal fusion devices and existing expandable spinal cages in general. The desire for a design of an expandable spinal cage is based on four key goals: 1) To make an implant that is more accessible to patients by reducing the overall cost of the procedure, 2) to use engineering knowledge to improve upon existing designs, 3) offer a fresh mechanical engineering mindset to a market dominated by the medical field, 4) and to reduce errors associated with multiple, different sized cages.

1.3 Literature Survey

1.3.1 Overview

The human spine plays a vital role in everyday life. Human health, balance and movement all rely on the stability of the vertebral column in completing everyday simple and complex tasks that help lead a normal life. When the vertebral column weakens or fails, many complications arise as a result that can lead to great risks of injury, discomfort, pain and in most severe cases, paralysis or death. The spine is the pathway for the central nervous system that sends messages from the receptors in the body to the brain. When there is a malfunction in that pathway, not only is it painful, but the affected area is can cause serious, irreparable nerve damage if untreated.

One example is the case of herniated or bulging disks shown in Figure 3. The vertebral disks act as cushion to keep the adjacent vertebra from touching and grinding of bones which
can be very painful. Similar to a flat tire, if still in motion, not only will the rim and rotary disk suffer, but consequently, the axle will as well due to the displacement and forces acting upon it. If there is displacement in the spine between two vertebrae, consequently a pinched nerve can easily be produced. If the vertebrae go as far as to fracture, from impact or rubbing, caused by a degeneration of the unhealthy segments, there is a much more serious problem at hand.

1.3.2 History

The use of vertebral body replacements to perform corpectomies is a fairly new emerging technology developed within the past few decades and is rapidly growing in popularity. It involves the removing of damaged vertebral bodies and replacing them with an

Figure 3: Herniated Disk with Pinched Nerve (MayoClinic)
implant to act as the new vertebrae. This process is usually followed by spinal fusion in which autologous bone material, tissue or cells, is used from the damaged vertebra to fuse the new implant to the adjacent vertebrae. Within the past two decades, practice of spine fusion has grown with the increase of new technology. In particular, more spine cages have been developed and implemented within the past 20 years than ever before. Today, more than 300,000 spine fusion surgeries are estimated to take place each year in the United States, (Becker, 2003), to help individuals with fractured spine like the one seen on Figure 4.

![Figure 4: Vertebral Compression Fracture (Jointandspinesurgery.com)](image)

Fusion is a method first introduced by Russel Hibbs and Fred Albee in 1912 to cure tuberculosis of the spine, also known as Pott’s disease. Both surgeons used the method of harvesting autogenously bone graft to fuse the posterior joints together. The bone graft was often taken from the pelvis and from the posterior surface of the lamina to fuse the posterior facet joints (Peltier).
This approach was used for many years but proved to be unsuccessful due to the poor stability of using bone to fuse spinal joints as well as the unwanted side effects of bone graphing procedures. It wasn’t until 1940, when a neurosurgeon by the name of Ralph Bingham Cloward introduced his technique of Posterior Lumbosacral Interbody Fusion (PLIF). This method allowed fusing two vertebral bodies together into a single motion segment while maintaining them separated to allow the decompression of neural structures. This progress proved to be a milestone in spinal neurosurgery by introducing the approach that is still widely...
used today known as the Cloward Procedure. As technology advanced, so did the methods of Interbody Fusion. In 1987, the first non-bone implant was introduced in Europe with the Charite III Disc. The replacement disk was made of two metal alloy endplates and a unique sliding core and is still used today as a popular artificially disk replacement. It is inserted between two vertebrae to help restore disc space height (Spine Health, 2013)

Figure 7: Charité artificial disc (Mayoclinic)
Today, various spinal cages are commonly used for inter-body spinal fusion. Companies such as Zimmer, Stryker, DePuy and Ulrich and many more are all using different designs to meet the demand for spinal cages. According to the American Chiropractic Association, 31 million Americans (Jensen M, 1994) alone have back problems and predict that as much as 80% of the population will experience back problems at one point in their lives [4]. Most can be treated with physical therapy or painkillers, but for more severe cases, such as fractures, bone deterioration and disease, the problem calls for greater medical attention. It is these patients that suffer from more severe spinal column issues that stand to benefit the most from such devices. Thanks to innovation in engineering and biomechanics, engineers and surgeons have bridged the gap to help people with such problems to ensure that in time of unforeseen complications, they will still be able to live a normal life with the help of an implant.
2. Project Formulation

2.1 Overview

2.2 Project Objective

The purpose of this project is to greatly reduce the amount of sizes and parts needed to effectively perform a corpectomy, the procedure of replacing vertebrae in the spine. The common procedure has many flaws and as future engineers we feel that we can alleviate many of the issues in traditional spinal fusion procedures. By reducing the amount of cages from a pack of 20 pieces with many different sizes, the objective will be to design, test, and future market a “one size fits all” cage while still able to support the vertebral column like any implant currently on the market. Realistically, since the spine sizes greatly vary, creating one cage that could fit throughout any area in the spine would an extremely difficult task would take years of development and testing. However, for the 3 regions of the vertebral column, the thoracic and lumbar region will be targeted with a single cage which is a design that has yet to be developed on the market. The cervical region is drastically smaller in size due to the fact that it is located throughout neck and head and will not be considered for design in this project.

Our overall goal is to see the project from start to finish, using advanced problem solving techniques, such as the DMAIC problem solving technique. In this project, the DMAIC technique breaks down in the following order;

1. Define our problem of complex and inefficient spinal fusion techniques that do not allow for 100 percent fits
2. Finding different ways to measure and collect data
3. Analyzing the data that was recorded
4. Improving the overall design to achieve maximum results
5. Setting controls that prove the overall effectiveness of the information

Once a satisfied project direction has been achieved, the spinal cage design can be fabricated. Furthermore, testing it in “real world” situations by placing it through the rigors of multiple simulated forces similar to those of the spine will be the following step. If the multiple goals set out to accomplish are achieved, an expandable spinal cage that is: innovative, durable, and less expensive can be approved for future real world manufacturing.

2.3 Design Specifications

The greatest challenge to overcome with the vertebral body replacement in design is to produce an implant that is durable and long lasting with a higher expandable range than the leading replacements. Keeping that in mind, material and manufacturing processes are to be considered in order to achieve not only structural integrity but cost savings as well. Common materials used in the market today that are biocompatible within the human body include: titanium, polyether ether ketone (PEEK), and in some cases, carbon fiber. Characteristics for these materials will all be studied for consideration of this design. Furthermore, tolerances are a main concern in this project since the cage must expand to a precise measurement to fit the individuals undergoing this procedure. Once this device is installed and has fused over time
with the adjacent vertebral bodies, the cage is there for life. There is no maintenance or adjusting that will be necessary once in the body.

With the variation in bone sizes for each individual and for the spine sections the desired design is set to function for, the intent is to create something that will still have a precise adaptability for each patient. This means that the overall core structure of the implant must not exceed the diameter of the smallest vertebra that is to be replaced. As the vertebral bodies enlarge down the spine, several stamps or plates mating with the adjacent bodies will need to be used in order to provide stability for the device. This will require calculation of bending moments for plates as they will experience forces similar to that of a cantilever beam.

2.4 Constraints

To achieve the goals of designing a universal expandable cage that is effective and durable, we must understand the constraints that are associated in doing so. The anatomy of the spine and how it functions is not part of the mechanical engineering curriculum; therefore, this required extensive research on the subject. To meet the requirements of parameters a spinal cage must fall within, the constraints within the body were closely studied and evaluated. Material used in the human body will be discussed in a later section. In this section, the main focus will be on the geometric parameters to produce a successful design that will not interfere or obstruct organs, tissues, nerves or other anatomies surrounding the vertebral column. Figure #9 displays a typical human spine and as previously stated, the thoracic and lumbar region (beginning at T1 and L1) will be the points of interest.
Scientific journals were studied to find commonalities within sizes of the human spine to better understand the parameters of the constraints. In one study to find similarities between human and porcine spines for research purposes, 6 complete vertebral columns were measured (Busscher, 2010). The values obtained from the study of height measurements that were of interest for this project were populated in the table below.

<table>
<thead>
<tr>
<th></th>
<th>VBHa</th>
<th>STD. Dev.</th>
<th>VBHc</th>
<th>STD. Dev.</th>
<th>VBHp</th>
<th>STD. Dev.</th>
<th>IDH</th>
<th>STD. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>17.3</td>
<td>0.8</td>
<td>16.1</td>
<td>0.5</td>
<td>18.8</td>
<td>1.0</td>
<td>5.0</td>
<td>0.8</td>
</tr>
<tr>
<td>T2</td>
<td>17.9</td>
<td>1.4</td>
<td>16.7</td>
<td>0.9</td>
<td>19.1</td>
<td>0.8</td>
<td>4.5</td>
<td>0.6</td>
</tr>
<tr>
<td>T3</td>
<td>19.3</td>
<td>0.8</td>
<td>17.5</td>
<td>0.4</td>
<td>19.6</td>
<td>1.0</td>
<td>4.7</td>
<td>0.8</td>
</tr>
<tr>
<td>T4</td>
<td>19.9</td>
<td>0.8</td>
<td>17.9</td>
<td>0.8</td>
<td>20.6</td>
<td>1.2</td>
<td>4.7</td>
<td>0.3</td>
</tr>
<tr>
<td>T5</td>
<td>19.1</td>
<td>3.2</td>
<td>17.6</td>
<td>2.5</td>
<td>21.0</td>
<td>1.6</td>
<td>4.8</td>
<td>1.1</td>
</tr>
<tr>
<td>T6</td>
<td>19.1</td>
<td>3.0</td>
<td>18.1</td>
<td>2.5</td>
<td>21.7</td>
<td>2.0</td>
<td>5.3</td>
<td>1.1</td>
</tr>
<tr>
<td>T7</td>
<td>19.8</td>
<td>1.1</td>
<td>19.3</td>
<td>1.6</td>
<td>22.4</td>
<td>1.7</td>
<td>5.2</td>
<td>0.7</td>
</tr>
<tr>
<td>T8</td>
<td>20.1</td>
<td>2.8</td>
<td>19.8</td>
<td>1.2</td>
<td>22.7</td>
<td>1.5</td>
<td>4.9</td>
<td>1.1</td>
</tr>
<tr>
<td>T9</td>
<td>21.4</td>
<td>1.6</td>
<td>21.3</td>
<td>1.2</td>
<td>23.7</td>
<td>2.0</td>
<td>4.8</td>
<td>1.0</td>
</tr>
<tr>
<td>T10</td>
<td>23.3</td>
<td>1.6</td>
<td>22.2</td>
<td>1.6</td>
<td>25.3</td>
<td>1.6</td>
<td>5.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*Figure 9: Human Spine Anatomy (Backpain-guide.com)*
Measurement of the anterior (VBHa), center (VBHc) and posterior (VBHp) heights were obtained, along with the disc height (IDH) of the adjacent disc. The abbreviations are measured as follows.

When an expandable spine cage is implanted into the spine, the damaged vertebral body is removed along with the two adjacent disks surrounding it. Therefore, the measurements of the disk heights are also taken into consideration throughout the design
process. The smallest height obtained by the experiment is the gap if replacing a T1 vertebra. The maximum height of T1 is 18.8mm with a standard deviation of 1mm. With the removing the adjacent disks; another 9.5mm opening with a standard deviation of 1.4mm will be present. A minimum opening of 28.3mm will be the desired target for the design, more or less depending of standard deviation.

The maximum height targeted for the expansion of the cage will be targeted for the replacement of the tallest vertebra. From the chart, we can observe that it is located at L3, with a maximum displacement of 54.3mm after taking adjacent disks into account. This will be the desired maximum height with a total expansion rate of 26mm. This is just the initial target but standard deviation will be taken into account for the design.

For the diameter constraints, we obtained another study in which the measurements of 174 subjects’ vertebral columns were studied at various age groups (Kolta, 2011). The table below shows the results along with the geometric parameters from which they are referenced.
Baseline values of geometric parameters of thoracic and lumbar vertebrae in different age ranges.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>20–30 years (N = 15)</th>
<th>31–40 years (N = 38)</th>
<th>55–60 years (N = 65)</th>
<th>70–80 years (N = 56)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal cross-sectional area (mm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracic spine (T4–T12)</td>
<td>610.9 ± 130.3</td>
<td>639.4 ± 134.7</td>
<td>689.6 ± 156.6</td>
<td>683.7 ± 146.4</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>851.7 ± 53.1</td>
<td>906.0 ± 52.9</td>
<td>949.2 ± 110.7</td>
<td>928.1 ± 108.7</td>
</tr>
<tr>
<td>Superior end plate depth (mm)</td>
<td>28.0 ± 2.2</td>
<td>28.8 ± 2.4</td>
<td>30.4 ± 3.1</td>
<td>29.5 ± 2.8</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>32.0 ± 0.6</td>
<td>33.1 ± 0.2</td>
<td>33.5 ± 1.9</td>
<td>33.2 ± 1.9</td>
</tr>
<tr>
<td>Inferior end plate depth (mm)</td>
<td>25.3 ± 1.7</td>
<td>30.0 ± 1.8</td>
<td>30.6 ± 2.6</td>
<td>30.6 ± 2.4</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>33.9 ± 1.3</td>
<td>34.8 ± 1.0</td>
<td>35.1 ± 2.1</td>
<td>35.0 ± 2.1</td>
</tr>
<tr>
<td>Superior end plate width (mm)</td>
<td>31.8 ± 4.1</td>
<td>32.5 ± 4.2</td>
<td>34.0 ± 4.8</td>
<td>33.8 ± 4.3</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>42.3 ± 2.4</td>
<td>43.6 ± 2.2</td>
<td>45.0 ± 3.3</td>
<td>44.3 ± 3.5</td>
</tr>
<tr>
<td>Inferior end plate width (mm)</td>
<td>33.9 ± 3.9</td>
<td>34.3 ± 3.9</td>
<td>36.1 ± 4.7</td>
<td>35.8 ± 4.7</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>45.0 ± 1.9</td>
<td>46.5 ± 2.1</td>
<td>48.0 ± 3.4</td>
<td>47.6 ± 3.4</td>
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<tr>
<td>Vertebral body volume (mm³)</td>
<td>1361.2 ± 4329.2</td>
<td>1427.3 ± 4568.0</td>
<td>15215.6 ± 5247.2</td>
<td>14951.8 ± 4857.2</td>
</tr>
<tr>
<td>Thoracic spine (T4–T12)</td>
<td>25615.5 ± 1642.8</td>
<td>27474.7 ± 1467.7</td>
<td>28470.8 ± 4250.0</td>
<td>27454.7 ± 3820.4</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td>15.6 ± 2.2</td>
<td>19.7 ± 2.5</td>
<td>19.5 ± 2.9</td>
<td>19.2 ± 3.0</td>
</tr>
<tr>
<td>Anterior height (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracic spine (T4–T12)</td>
<td>26.9 ± 0.8</td>
<td>27.3 ± 0.7</td>
<td>27.1 ± 1.8</td>
<td>26.7 ± 1.9</td>
</tr>
<tr>
<td>Lumbar spine (L1–L4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Vertebrae Dimensions for Multiple Age Groups (Kolta, 2011)

S. Kolta et al. / Bone 50 (2012) 777–783

Fig. 2. The 3D geometric parameters of the vertebral body measured by 3D-XA method.

Figure 11: References to Dimension Measurements (Kolta, 2011)
To keep the number of stability adaptable plates used for the design minimal, a common ground between the variations of estimated diameters must be found. The objective of the design is to reduce the cages and parts in the operating room while still performing the necessary function it needs to. That being said, three common sizes will be evaluated for support and be interchangeable in the operating room. This is a practice that is common in spinal cages on the market today.

Several differences in spine sizes can be observe from Table #2. First, the expansion of vertebral depths and widths as the age group increases. A safe assumption can be made that over time, as the body ages, so do the bones making the years of constant thrust loading compress and expand the vertebrae radially. For this reason, the dimensions of the age group of 20-30 years of age will be considered for the design of the plates. If the plates are designed with an increased design factor, that will compensate for the radial expansion over time to prevent failure.

Secondly, it is observed from the measurements, that the lower the vertebra falls on the spine, the bottom and top faces change shape. Going from a circular shape in the thoracic region and expanding to a more oval shape into the lumbar region. Many vertebral body replacements on the market today do not take this change in shape into account when designing of the interchangeable stamps. For this project, it will be considered because in theory is would provide more stability.

After evaluating the sizes of the spine, three replacement stability plates are considered for design. Starting with a perfect circular plate with a diameter of 1 inch (approx. 25mm),
followed by two oval shaped plates of dimensions 1.1 x 1.2 in (approx. 28x30mm), and 1.2 x 1.4in. (approx. 30x35mm).
3. Design Alternatives

3.1 Overview of Conceptual Design

Most common expandable cages currently on the market are modeled very similar to one another. It is these current devices that have been used as a starting point to understand the concept behind them and why they are designed in a very similar manner. Most expandable cages contain four major components that are essential to imitate the functionality of vertebrae that is absent and achieve the purpose of why they are used. For this report, these four components will be referred to as: the base, expander, and top and bottom plates. The base of the structure usually sits on the bottom half of the replacement and is usually wider and thicker than the expander. This part serves as the basis for which the vertebral body replacement is designed around and provides the structural integrity required to support the loads that the cage will experience throughout its lifetime. The expander usually sits within the cage and provides a way to adjust the replacement vertically to the position required in order to fill the void of the removed vertebrae. The last two key components are the top and bottom plates which offer stability for the whole system. Because everybody has a similar, yet, unique bone structure and sizes, the plates are usually interchangeable. This provides the opportunity to match the closest diameter to the surrounding vertebral bodies to keep the bone from hanging over the cage and possibly shifting or slipping.

The concept of the desired design will stay similar to the one stated above but with an a new idea to push the limits by designing a cage that will be universal, in the sense that it will be able to fit in any part of the thoracic and lumbar region of the spine.
3.2 Design Alternative 1

![Figure 12: Alternate Design 1](image)

This design takes into account the stability of a cube and the increased contact area a sliding block has compared to traditional designs that use threaded rods. This mechanism is compressed using four sets of cubes with angled sides running parallel to one another. When intact, the cubes can slide along each other’s sides and form a stiff unit that lends itself very well for increasing the overall height of the unit, allowing the adjustability to engage.

As mentioned previously, the surface area of the contact area is increased with the use of the cube design, allowing for a stronger connection between the pieces of the unit. The simplicity of the design allows for the manufacturability of the unit to favor a low cost overall pricing. Another benefit of the design is the overall height of the unit can be easily increased by adding taller side walls and substituting the same top and bottom blocks for increased variations of the final unit.
This design does have some drawbacks: for instance the unit design is only as strong as the joining screw. If the joining screw fails, the entire system will fail without some type of retention safety mechanism.

3.3 Design Alternative 2

This prototype is a simple cylinder hollowed out to allow moment of two side walls. The walls of the cylinder allow for its adjustability to either expand or contract. Which when moved closer to each other expands the system and vice versa. They also will provide the support of the structure and will maintain most of the load. Both base and top plates are fitted with holes to allow for bone graph growth. These plates are also fitted with anchor pins that will allow the placing surgeon to secure it firmly to the bone. The main point of moment other then the walls themselves will be located inside the base and top plates. The movement will be done by a screw of sorts that is similar to one associated with an expandable wrench. There will be four sites for these screws so that the plates move in a uniform fashion.
The benefits associated with this prototype vary. This system overall will be very stable and will provide ample support during the healing process. The hollowed design will allow for less material in the manufacturing process which in turn will reduce the cost to the patient. Lastly, the simple design will allow for easy placement and avoid any complications.

The disadvantage of this prototype heavily outweighs its benefits. The first being the movement of the walls up and down the supporting plates. As the plates move closer together there is less room for contact with the plates and walls so natural complication will arise. Upon placement the screwing system poses a problem due in part to the four points needed to be screwed at the same time. Lastly the simplicity of design may only be a disguise to hide its true complications. Too many questions can be asked about the system which is its ultimate disadvantage.
3.4 Design Alternative 3

![Figure 14: Alternate Design 3](image)

The base plates of the expandable spinal cage will be the main portions of the spinal cage that will grab and hold on to the vertebrae. This will ultimately hold the cage in place between the two sections and allow the fusion to begin. Each plate will have a number of teeth that will aid in grabbing the bone most likely digging a little into the vertebrae which in turn will ensure that the system stays in place will the fusion process goes on. These base plates will also have the most allowable area as possible to ensure the system is stable in between the two vertebrae and to also help with any forces that the spinal column can and will carry.

The base cylinder will be the only portion of the cage to which the surgeon can and will hold the system with the required tools. This portion of the device will also include pathways
through the shape that will allow the bone graph material to grow out of and around. The base cylinder’s main function after support will be to facilitate cell grow through its openings and also aid in the expansion and contraction of the upper cylinder. Lastly, the base cylinder will have a threaded gear system which will be used to expand or contract the moveable portion of the spinal cage to the desired length.

The top cylinder of the spinal cage will be the only moving portion of the whole system. It will slide in and out of the base cylinder to whatever length desired by the surgeon. This expanding portion will be attached to the upper basest plate. This portion of the system will have threads along its length and along with the gear system on the base cylinder will allow the movable portion to either expand or contract based on the required measurements.
3.5 Design Alternative 4

The base cylinder is of a simple design consisting of a 3mm thick cylinder with an outside diameter of 22 mm, 16mm inside diameter and a height of 27 mm. The purpose of this cylinder is not only to provide a base for the system and as well as housing for the other components but also a place for the screwing mechanism to attach. This is done by having a 1.5 mm deep channel that will allow a special key to float in and also stop the screwing mechanism from detaching.
The screwing mechanism is a cylinder with an outside diameter of 28 mm and an inside diameter of 22 mm. This will allow it to fit nicely over the base cylinder. This piece is specially cut to allow the retaining key to slide in groves which ultimately mate with the base cylinder groove channel, thus locking the screwing mechanism to the base cylinder.
The locking key is design specifically to maintain the connection between the screwing mechanism and the base cylinder. The key consist of two parts which when placed inside the designated slots on the screwing mechanism come together and complete a circle. These keys lock together via retaining screws which insure a tight fit that will not disconnect.
The middle cylinder, or expander, which will be both lowered and raise by the screwing mechanism has an outside diameter of 16 mm and an inside diameter of 10 mm. The middle cylinder is threaded both inside and outside with a square thread with a pitch of 1 mm. This same thread is used on both the small cylinder and the screwing mechanism. The middle cylinder will expand and contract via the screwing mechanism and rest inside the base cylinder when not expanded. The top, most inner small cylinder will expand and lower via torque applied directly to it and rest inside the middle cylinder when not expanded. The top of the small cylinder will be fitted with a plate with a diameter of 22 mm to provide and stability to the system.
Figure 19: Alternate Design Middle Cylinder

Figure 20: Alternate Design 4 Top Cylinder
3.6 Feasibility Assessment

After designing the numerous design alternatives we can come to the conclusion of which general design would work best for our given situation. We had a few different designs that achieved similar results but the design that allowed for the most flexibility was a telescoping, tubular rod design with multiple levels. The compression lifting method in a few of the design alternatives is a stable design but does not allow for the needed height dimensions. Achieving the required height parameters can be considered the most important aspect of the entire project of building an expandable spinal cage and without it, is considered an overall failure to replacing the numerous expandable and non-expandable cages which are currently in the market.

3.7 Proposed Design
3.8 Discussion of Proposed Design

Our design will have the best aspects of current technology with our tweaks and unique designs to make a better product for patients and physicians. In order to make a cage that is universal and that can essentially fit in many regions in the thoracic and lumbar region, a cage with a wide range of expansion must be used. The proposed design can replace a vertebra as small as 1.1 inches in height when the displacement is zero at the initial state of the cage. In many cases in which much larger vertebrae need to be replaced, our design will have the capability to expand to height of 2.79 inches which can replace a wide variety of cages.

The proposed design consists of 6 major components; two or three core cylinders, one threaded twist ring, and two face plates. The core of the spinal cage includes two hollowed out and threaded cylinders that fit inside a main base cylinder, for a total of 3 levels of the spine cage for maximum expansion. When the cage is at its minimum position, it can fit in to a wide array of smaller vertebrae. A twist ring attached to the base level at the top of the cylinder. The twist ring, together with the second level of the cage, acts like a nut to a nut and bolt mechanism. When the ring is twisted, the second level then rises to expose the remainder of the cage.

For the final design, the top of the first level will have an opening where it meets the twist ring to allow a key or tool to be inserted. The tool used will be the counterpart to the gear thread that will be added to the bottom of the twist ring. When the tool in then inserted and rotated clockwise, it will cause the ring to turn radially, acting as a rack and pinion.
The top and bottom plates will help fuse the top and lower vertebrae to the cage. For the development of the cage, the top and bottom plates will include a grip on the surface to keep the cage from slipping at the time it is installed. 3 to 4 spikes will be designed on the face as well to further reinforce the stability of the cage into the vertebrae.
4. Project Management

4.1 Overview

Keeping the overall direction of the project going in a productive direction is as an important factor as the final design of the expandable cage itself. You achieve this efficiency by outlining team roles and expectations before the project gets heavily underway. The breakdown of tasks, timelines, and roles are outlined in the next sections.

4.2 Breakdown of responsibilities

<table>
<thead>
<tr>
<th>Justin Crisp</th>
<th>Christopher Dominguez</th>
<th>Peter Medrano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculations</td>
<td>Final design drawings and simulation</td>
<td>Report Designer and Composer</td>
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<tr>
<td>FEA computations</td>
<td>Research and compatibility</td>
<td>Cost analysis</td>
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<tr>
<td>Research and sustainability</td>
<td>FEA Analysis and Simulations</td>
<td>Prototype Design Manufacturing</td>
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*Table 3: Group Member Responsibilities*

4.3 Time allocation breakdown

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<thead>
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<th>Justin Crisp</th>
<th>Christopher Dominguez</th>
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<td>Design Validation</td>
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<td>Product Drawings</td>
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<tr>
<td>Prototyping and Testing</td>
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### 4.4 Gantt chart Timeline

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*Table 5: Work Timeline*
5. Engineering Design and Analysis

5.1 Structural Design

In order to determine that the spinal cage will not fail, Finite Element Analysis on SolidWorks was calculated for critical parts that experience the highest loads. The patient undergoing this procedure will be made aware beforehand of the constraints that he or she will have post surgery.

In a study done by Julius Wolff Institute in Berlin, loads on vertebral body replacements during locomotion were studied. 5 patients with an average weight of 143lbs were observed and spikes in spinal compression loads were obtained. The maximum force experienced was 166lbs when walking at a moderate pace. This value was not significantly higher that the persons weight. For our particular design, each patient will be recommended to not exceed a weight of 300lbs.

5.1.1 Extender Analysis

When the cage is inserted to its maximum length of 2.36 inches, the highest stress in the entire system will be experienced through the threads that are engaged of the middle piece (extender). Running the simulation with the bottom 5 threads fixed upward and a distributed down force of 300lbs on the top face of the upper 5 threads, the following results were obtained.
The titanium used for this spine cage has a yield strength of 1.05 GPa and the maximum von Mises experience are well below that at 410 Mpa. This gives us a safety factor of 2.6, and given
that 300 lbs is already excessive for a typical individual, the extender proves to be more than reliable.

### 5.1.2 Plate Analysis

The plates located at the top and bottom of the spine cage provide stability for the cage to prevent it from slipping or moving. The same 300 lbs force applies to the top area and because the there is a small threaded screw in the center of the part. As a result of the design, it leaves a large area of to hang over the rest of the cage with the force pushing up or down on it, depending on location.

![Figure 24: Plate von Mises Stress and Factor of Safety Analysis](image)

After running the simulation, it is observed that the maximum stresses are located in the threaded area, due to the smaller area that’s being compressed on. A factor of safety of 2 was obtained and is still acceptable for this design.

### 5.1.3 Base Analysis
The approach for the base analysis simulation differs from the other parts of the cage in the sense that it does not have and threads that are under a high amount of loading. The point of interest for the base are the holes in which the tightening screws go through in order to stop the ring from moving and lock the cage. The distance from the top of the base to where the drill hole for the threads is 1/16 of an inch. This raises some concern as to if it is enough material to withhold the targeted maximum load of 300 lbs without deforming the cage enough to where the limited material could crack and fail. The results are shown below.

As predicted, the area right above the holes where the maximum deformation occurs. The maximum deformation is approximately .003 mm which acceptable and shows that it will not fail. The maximum von Mises stresses located at those points 78MPa which is well below the 10.5 GPa yield strength. The minimum factor of safety under this load is 13 and from that value it is concluded that the material is not expected to fail under the maximum load.
5.2 Force & Stress Analysis

5.2.1 Analysis of Screw

After a final design was chosen an overall analysis had to be completed to ensure that the design would maintain its integrity. This analysis also served as a means of determining what our design would need to include ensuring safety. First and foremost our design simply consists of three cylinders, with that being said the middle cylinder also having the smallest diameter would be the main focus of all the loads for the system which is the defining assumption for our analysis. Starting on the threads of the middle cylinder certain values must be known to ensure accuracy of the analysis. Those being the lead(l), outer diameter(Do), inner diameter(Di), mean diameter(Dm), thread depth of (1/40)in, root diameter(Dr), Force(F) and lastly friction coefficient(f). To begin the analysis we established that an average load of 300 pounds would be applied to our system which would serve as the force for our calculations. From that point using obtained equations from Shigley’s Mechanical Engineering Design text book we were able to determine that the force required to raise the load and lower.

\[
\begin{align*}
PL & := \frac{F\left(f - \frac{f\cdot l'}{\pi \cdot Dm}\right)}{1 + \frac{f\cdot l'}{\pi \cdot Dm}} = -12.732 \\
PR & := \frac{F\left(\frac{f}{\pi \cdot Dm}\right) + f}{1 - \frac{f\cdot l'}{\pi \cdot Dm}} = 12.732
\end{align*}
\]

*Equation 1: Force req’d to lower*

*Equation 2: Force req’d to raise*

Ultimately these values are 12.7 and -12.7psi as seen above. Next we approached the torque required to raise and lower the middle cylinder via the thread. After careful calculations we determined the torque needed to raise and lower the screw.
The values as seen above are 2.37 and -2.37 lbf. The negative values show that the system is not self locking and would slowly contract due to the force applied. This means that extra design considerations must be taken to ensure that our system doesn’t pose a problem for its intended recipient. Lastly with other parameters on hand we found the maximum shear stress on the screw body, the axial stress on the screw body and more importantly the efficiency.

\[
\sigma = \frac{4F}{\pi Dr^2} = 2.245 \times 10^3
\]

\[
\tau = \frac{16Tr}{\pi Dr^3} = 173.226
\]

Equation 5: Stress on body of screw

Equation 6: Shear on body of screw

In the case of efficiency we first must assume that the system does not experience friction to develop a base line so to speak as represented by the equation below.

\[
To := \frac{F1}{2\pi} = 2.387
\]

Equation 7: Theoretical torque without friction

This value and the value of torque required to raise the load were used to determine the systems efficiency. This untimely means that the threads used are 100% efficient as shown below.
5.3 Buckling Analysis

Another main consideration that we took into account for our analysis was buckling of a thin walled member due to an applied load. To begin we needed to determine a few values to include area moment of inertia (I), Area of the cross section (A) and lastly the maximum length of our system (L). With that in mind we first determined the area moment and cross section area of our system.

\[
e' = \frac{F \cdot I}{2 \pi \cdot Tr} = 1
\]

*Equation 8: Efficiency*

\[
I := \frac{\pi \cdot \left( D_o^4 - D_i^4 \right)}{64} = 1.33 \times 10^{-3}
\]

*Equation 9: Area moment of inertia*

\[
A' := \frac{\pi \cdot \left( D_o^4 - D_i^4 \right)}{4} = 0.021
\]

*Equation 10: Cross sectional area*

With these values we were ultimately able to determine the critical load (Pcr) needed for the system to buckle and the critical stress due to the critical load, both of which are calculated for titanium.
Lastly using the assumed load applied to each individual cylinder we found the deformation of the system at the center point of connection.

\[ \delta L := \frac{F \cdot L_1}{A_1 \cdot E} + \frac{F \cdot L_2}{A_2 \cdot E} = 2.906 \cdot 10^{-4} \]

*Equation 13: Deformation due to loading*

This value proved to be smaller than one thousandths of an inch which is very acceptable since deformation could prove to be very hazardous.

### 5.4 Material Selection

For the majority of prosthetic implants and surgical procedures that place devices in the body, titanium is generally the material of choice. This can be attributed to the many characteristics of titanium that make it favorable over other metals or materials. For instance, titanium has excellent biocompatibility and corrosion resistance (Pohler, 2000). The corrosion resistance of titanium is a well documented characteristic and can be attributed to its good affinity to oxygen, carbon and nitrogen and therefore tendency to form a passivating layer (T. Wierzchoń, 1997). It is these characteristics that allow it to be the metal of choice for prosthesis...
procedures. Besides titanium, the other popular material for spinal cages is polyetheretherketone (PEEK). It has been shown to have many of the benefits of titanium and in many factors surpasses the overall quality of traditional titanium cages due to its attractive material as a structural graft due to its inert chemical nature and its comparable modulus of elasticity to bone (Kasliwal, 2013). Even though PEEK has been shown to have attractive and beneficial characteristics, it cannot achieve the overall strength and manufacturability of a titanium cage.

5.5 Finite Element Analysis

Considering our spinal cage system a step shaft we attempted to analyze the system using finite element solutions. First we modeled the system with its spring equivalents for each rod which are dependent on area and length along with Young’s modulus for the material. These values provided the spring constants (K).

\[ K_1 := \frac{E \cdot A_1}{L_1} = 1.351 \cdot 10^6 \]

*Equation 14: spring constant for the small rod*

\[ K_2 := \frac{E \cdot A_2}{L_2} = 4.371 \cdot 10^6 \]

*Equation 15: spring constant for the base cylinder*

The first value represents the spring constant for the smallest cylinder and the second value is for the base cylinder both of which are in pounds per inch. Determining these values along with
assuming both ends of our system would experience no deflection we were then able to calculate the deflection between the small cylinder and base cylinder.

\[ U_2 := \frac{F - U_3 \cdot 0 - K_1 \cdot U_1}{K_1} = -7.78 \cdot 10^{-4} \]

*Equation 16: deflection at center point of system*

Once we found the values that were the easiest to calculate we set out on matrices operations. Using a simple three by three matrix along with a one by three matrix we were able to determine the reaction forces for the system.

\[
Y := \begin{bmatrix}
  K_1 & -K_1 & 0 \\
  -K_1 & (K_1 + K_2) & -K_2 \\
  0 & -K_2 & K_2
\end{bmatrix}
\]

*Equation 17: spring constant matrix*

\[
W := \begin{bmatrix}
  U_1 \\
  U_2 \\
  U_3
\end{bmatrix}
\]

*Equation 18: deflection matrix*

\[
Y \cdot W = \begin{bmatrix}
  2.403 \cdot 10^3 \\
  -1.017 \cdot 10^4 \\
  7.771 \cdot 10^3
\end{bmatrix}
\]

*Equation 19: reaction forces*

The values above then aided in finding the internal reaction forces of the system by repeating the matrix operations but this time only using a two by two matrix with a one by two matrix.
\[ q := \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \]

*Equation 20: spring constant matrix*

\[ s := \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \]

*Equation 21: deflection matrix*

\[ w := \begin{bmatrix} K_2 & -K_2 \\ -K_2 & K_2 \end{bmatrix} \]

*Equation 22: spring constant matrix*

\[ d := \begin{bmatrix} U_2 \\ U_3 \end{bmatrix} \]

*Equation 23: deflection matrix*

\[ q \cdot s = \begin{bmatrix} 2.403 \cdot 10^3 \\ -2.403 \cdot 10^3 \end{bmatrix} \]

*Equation 24: internal reaction forces of smaller cylinder*

\[ w \cdot d = \begin{bmatrix} -7.771 \cdot 10^3 \\ 7.771 \cdot 10^3 \end{bmatrix} \]

*Equation 25: internal reaction forces for base cylinder*

The accuracy of these values will be checked using computer aided finite element analysis due to the overall complexity of these calculations. We can say safely that the values are not correct and further analysis is need to ensure correct values.
6. Design Overview

6.1 Cost Analysis

Much consideration was needed as we finalized our expandable spinal cage. As only a select few material can be implanted in a body our selection was very slim but somewhat easy. So with that knowledge we chose the strongest material to be titanium 6Al-4V as our final design material. The price for a one foot long sold titanium rod with a diameter of 1.25 inches was $179.94. This extra outer diameter will allow us wiggle room so to speak when it comes to machining later. As with our prototype the same machining processes will be followed on the final design which will include boring which is essentially drilling a hole to hollow the rod, tapping which is applying a thread to the inner diameter and turning which consist of milling down the outer diameter to a smaller desired diameter and later applying an outer thread. Since titanium is a very hard metal to work with when it comes to machining processes; The cost associated with these techniques are very high. Ultimately the estimated cost of our final design to fabricate would roughly be $7123.82, this price includes materials as well. Titanium was our final material chose because of its high strength and more importantly it is the strongest of the select few materials that can be implanted in the body. Its strength will ensure that the implant will sustain the loads associated with the spine will maintaining it structural integrity. This was the best material and provided the most safety for the desired application.
7. Prototype Construction

7.1 Description of Prototype
The physical prototype will be made of different materials than the actual model which can be placed inside the body. The physical prototype will serve as a proof of concept and will be used to display the ideal final design. The prototype is consisted of various pieces of aluminum rod with one three-dimensionally printed spinning ring. The spinning ring was manufactured using a three-dimensional printer due to the complexity of the gear teeth that are used to spin the ring with the corresponding tool.
7.3 Prototype Design

![Prototype Final Assembly](image)

**Figure 26: Prototype Final Assembly**

### 7.3 Parts List

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*Table 6: Parts list*
7.4 Construction

To aid in the prototyping of our expandable spinal cage we will be using both three-dimensional printing methods and metal fabrication. The three-dimensional printing is a process that uses additive material to add layer upon layer of material to build virtually any design. The material is comprised of ABS plastic for our specific application but can also be done performed with metals and ceramics. This method does not require a support structure during the modeling portion due in part to the shape being built out of nothing and on a table. The second manufacturing technique that is needed for the prototype is metal fabrication technique which uses different type of machinery to shape metals rods to the desired specifications. Our prototype will be comprised of four main parts: two base plates one being on the bottom and one on top, Also a base cylinder and lastly the expanding portion of the cage. The final prototype will be comprised of titanium so that it can be properly tested and validated and will serve as our final assembly.

7.5 Prototype Cost Analysis

As the prototype is our main window into what can be achieved with our final design many considerations were taken to ensure that prototype cost were minimized but also data could be collected and compared with the final design. Material selection was a key component of our prototype and overall data calculation. With that being said 7075-T6 aluminum was our best selection due in part to its average rating for machinability and low price. One foot with a diameter of 1.25 inches cost $16.29. This was chosen to ensure that enough material would be present to machine away in later processes. The three main machining techniques used in the
machining process were boring which is essentially drilling a hole to hollow the rod, tapping which is applying a thread to the inner diameter and turning which consist of milling down the outer diameter to a smaller desired diameter and later applying an outer thread. Both the base cylinder and the middle cylinder were tapped to allow telescoping of the whole system. All three cylinders were bored to a desired inner diameter to maximize volume but also maintain structural integrity. Lastly the middle and smallest cylinder must be turned to reduce their outside diameter also to add threads need for telescoping. These machine cost plus materials were estimated at $100.00 for one complete unit. Upon completion of the aluminum prototype simulation software was utilized to determine max loading values. This brings us back to why we incorporated aluminum 7075. This was mainly due to the properties of this material will yield values close to half of our final product values made from titanium 6Al-4V. This method provided us with a feasible method of prototyping without incurring high cost associated with using the final build material.
8. Testing and Evaluation

8.1 Design and Description of Experiments

The industry over time has found new and innovative ways to test the overall strength of expandable spinal cages. The methods that have been covered thus far in regards to our design are based on simulation studies of forces that act in a predetermined or hypothesized manner. More accurate stress and strain calculations can be achieved if a real world element is introduced as measuring and experimentation tool. One of these, “real-world” style of experiments was performed by a group of experts at the University of South Florida. There, they dissected human cadavers and installed spinal cages along the spines of the cadavers. Each newly installed spinal cage and cadaver underwent numerous testing loads (Aghayeva, 2013). Similar tests can be undertaken to test the loads on the expandable spinal cage being introduced in this report.

*Figure 27 Frozen cadaver undergoing stress testing (Aghayeva, 2013)*
8.2 Improvement of the Design

Improvements of the current design can and will be ongoing to keep abreast with the ever increasing advancements in technology. These may include but are not limited to new materials that are found to be compatible with the body and manufacturing processes that may aid in increased strength and reliability of the system. These are ultimately the main focus points when dealing with future improvements. With material selections of the current market there are only a few possible selections for the human body. With that being said as time passes and the market expands it is certain that materials will be found or created to further increase material variety. It is key that future models be updated accordingly with advancements in materials. Specifically our system would benefit from an adjustment in diameter of the middle cylinder which in turn would increase the overall volume of the system. These means that the there would be more contained bone graph to assist in graphing time and area. These considerations would greatly benefit our spinal cage system and increase the overall desirability of the system.

8.3 Discussion

Testing for our spinal cage prototype will be done with two main methods. The first of these will be done with computer aided design programs and finite element analysis software. In this processes we will design and test our spinal cage virtually and also analyze it to find the max loads, shear stresses also to include the factors of safety and failure rates. This vital step will allow us to redesign any component that does not meet the desired specification. This step
will also save money in the long run due in part to the accessibility of the software from home and more importantly remove any flaws associated with our design. Lastly we will rapid prototype the design to incorporate an overall functionality test. In this process our aim is not at structurally testing the device but to see if it can actually function as desired. This means that it expands and contracts, that it is the right size for the intend area of implantation and lastly is free of any discrepancies that would hinder future performance. Once these milestones have been reached the final production step and validation will begin. Validation of our final prototype will be real world structural load testing. In this aspect of our time line we plan on testing our design by not only applying loads to the device via machine aided applications but also by real world scenarios. Our hope is to expose and points of failure and more importantly how we can improve these points.
9. Design Considerations

9.1 Assembly and Disassembly

When fully disassembled the expandable spinal cage is made up of 6 different pieces that when assembled, come together to form a dual level expandable spinal cage. When combined to form dual level expandable spinal cage, it can reach its maximum height of 2.36 inches without sacrificing the strength of a more compact system. In order to fit in smaller vertebrae, the system also has the ability to become a one level system to improve fit along the smaller vertebrae which are present for example in the cervix region along the upper portion of the spine.

![Figure 28 Single level Assembly](image)
9.1.2 Steps for Assembly

Figure 29: Double level assembly

Figure 30: Assembly - Step 1
Figure 31: Assembly - Step 2

Figure 32: Assembly - Step 3
Figure 33: Assembly - Step 4

Figure 34: Assembly - Step 5
9.2 Full Part Photo View

Figure 35: Base 2

Figure 36: Spinning Ring
Figure 37: Contact Plate

Figure 38: Middle sized contact plate
9.2 Maintenance of the System

An expandable spinal cage is designed to have zero maintenance during the life of cage. That is why the testing data was done with abnormally high parameters because a failure would
be catastrophic. It is this rigorous testing phase before the implant is ever installed to allow it to be maintenance free.

9.3 Risk Assessment

As with any medical procedure certain precautions must be taken before and after to ensure the highest success rate. In the case of spinal cages any recipient of the system will have lifelong limitation that one must be not only be aware of but also take very seriously. Major risks come in the form of physical activity whether it is playing a sport or working out individually. Recipients must refrain from partaking in any physical sport both contact and none contact as sudden movements, jerking contacts or motions and the overall forces on the body could cause the system to be dislodged, damage surrounding tissue or even fail. This does not mean one cannot be active this only suggest that precautions be addressed before any activity done. A healthy life is a happy life which would suggest that one should remain active and one way to achieve that is to work out individually. There are a lot less chances for a recipient to hurt themselves when the work out individually but there is always the possibility. While maintaining personal fitness one cannot, as any gym enthusiast would say "over do it". High impact and weight lifting are activities that should not be done at any time if you are fitted with spinal cages as these too can ultimately damage the body or system. It is suggested that any activity be discussed with any qualified medical physician to ensure that all limitations and guideline mapped out and followed.
10. Conclusion

10.1 Conclusion and Recommendation

We began this project with an overall goal of how we wanted to improve the expandable spinal cage market and do so by using the skills we have developed as undergraduate engineering students. This broad goal of improvement became a plan of action that allowed us to tackle the problems one by one and finding new ways to fix the problems with existing spinal cages. One of these goals for instance, was the inefficiency that was facing the market in regards to the numerous amounts of spinal cages that are being used for a given patient. Ulrich Medical™ for instance, has numerous cage adaptors to reach a height of 2.36 inches from .75 inches, when our cage can achieve similar heights without the need for so many adaptors. It is these design consistencies that we are hoping will allow for less expensive cages in the long term. Not only does the cage have less material and therefore lower costs, the fewer materials allow for a more intelligent installation process with fewer possibilities for error. We set out to achieve these goals and based on our overall design have achieved them.

To achieve the desired goal of this project and create a new type of expandable spine cage, it required a lot of innovative thinking. The major obstacle that was faced was how we were going to push the limits by designing a cage that can expand over double its size whilst still holding its structural integrity. To our knowledge, this feat has not been accomplished in the past and there is not a cage like it on the market today. How we manufactured the prototype was also a big concern to keep cost low for three unemployed students. To accomplish this, rod
and thread sizes were all standard sizes, with the exception of shaving off some of the rods. Working with a cage so small, choosing wall thicknesses that would be strong enough to hold the required loads once they were threaded was a big accomplishment. Since the cage could virtually be used in the entire thoracic and lumbar region, vertebrae diameters had to be carefully researched to make sure that the cage was not too wide to fit in a smaller area. All of the goals of we set out to accomplished were achieve. A cage was created to be used in any part of the thoracic and lumbar region and designed not to fail under an exaggerated load it would most likely never experience.

10.2 Commercialization Prospects of the Product

The product with respect to the tens of other expandable cages in the market is highly unique and shows what fresh minds can come up with limited resources. Having more than just two lifting levels increases the heights that are achievable, hence allows for a wider range of replacements for different sized. The route of choice to make this a product a commercial success would be to file a patent for the design and then proceed to introduce it to market leaders.
Works Cited


