3D Thoracic Epidural Model

For use in Anesthesiology training

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1.0 INTRODUCTION

There is a need for a user-friendly, low-cost model to assist trainees in developing the skills required for thoracic epidural placement. Commonly used in chest and abdominal surgeries, thoracic epidurals have been shown to improve outcomes both in terms of pain management and decreased opioid consumption and expedited functional recovery. For these many benefits, thoracic epidurals are included in the Enhanced Recovery after Surgery (ERAS) protocols worldwide. Residents often struggle during their first attempts at thoracic epidural placement. Learning the anatomy, visualizing the geometry of the needle approach, and developing a feel for the relevant tissues can prove challenging. Trainees can benefit from a simple model with which they can see and feel the anatomy and practice needle advancement, prior to performing the procedure on an actual patient. This Open-Source model can be created inexpensively at any university or other training institution with access to 3D-printing resources. The vertebral models and their corresponding discs were obtained from open-source cadaver CT scans.

1.1 Prerequisites

- Be familiar with 3D-printing
- Install a copy of MakerBot Desktop Printing Software (we used version 3.9.1)
- Download all required STL (Stereolithography) files

Disclaimer: Epidural placement is a procedure with significant risk of injury to the patient, including but not limited to injury to the spinal cord, infection, and bleeding. This model is designed for practice use only. Clinical epidural placement should be completed under supervision of a trained and certified anesthesiologist, and as part of an accredited anesthesiology training program.

2.0 LIST OF MATERIALS TO ASSEMBLE MODEL

1. MakerBot Replicator or equivalent high quality 3D-printer
2. Spool of PLA filament (.2 kg)
3. Spool of TPU filament (50g)
4. 5 boxes (5 oz.) of Knox Gelatin
5. Oomoo (silicone rubber) for Ligamentum Flavum
6. Bubble tea straw

7. Duct tape
8. Exacto knife
9. Epoxy
10. Medium grit sandpaper
11. Wire cutters/pliers
12. Soldering equipment (optional)
13. Circular base of plywood or fiberboard, ½" to ¾" thick, 6" diameter - can be made or purchased
14. One screw – flathead sheet metal screw, size #8, 1 1/2'"
15. Drill
16. 2.25 quart Rubbermaid plastic pitcher
17. 3" C-Clamp or Velcro tape

3.0 PROCEDURE

3.1 Outline

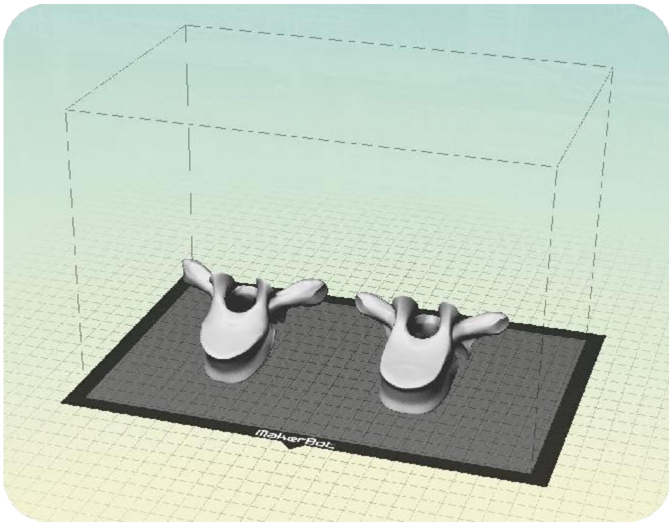
1. 3D-print five vertebrae (T7-T11) out of PLA
2. 3D-print four discs out of TPU
3. 3D-print mold for Ligamentum Flavum
4. Mold Oomoo to make Ligamentum Flavum
5. Assemble the epidural model
6. Make soft tissue around the spine out of gelatin

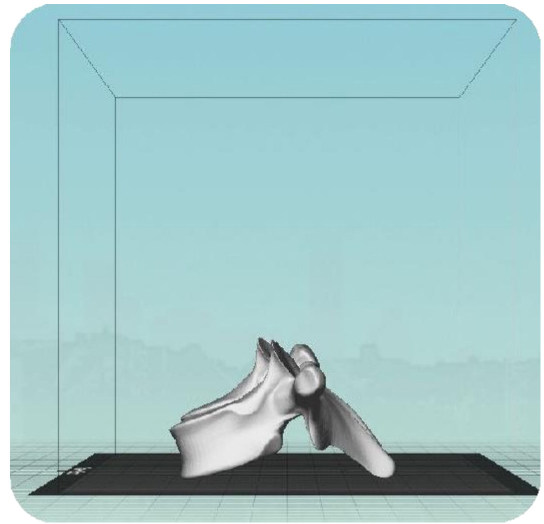
3.2 PLA Parts

3.2.2 Part Placement

VERTEBRAE

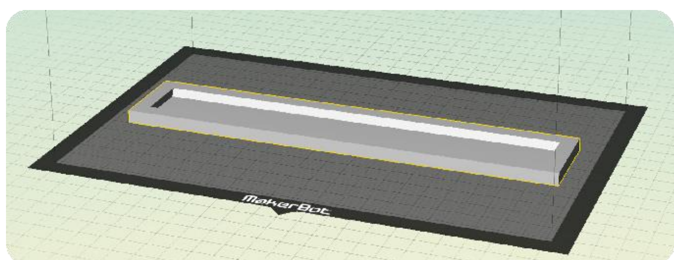
Due to the complex geometry and extremely thin regions of the vertebrae, proper part placement is vital for a successful print. After thorough testing in a 3D printing environment, we have found that the following photos show the most successful orientation for the vertebrae on the build plate. The use of support material makes this alignment possible. It is suggested to print no more than 2 vertebrae at a time. Orient each vertebra so that the superior facet joints are pointing to the top plane of the build space. Also, we suggest orienting them to maximize the amount of surface area that is touching the build plate, as shown in the pictures below.





LIGAMENTUM FLAVUM MOLD

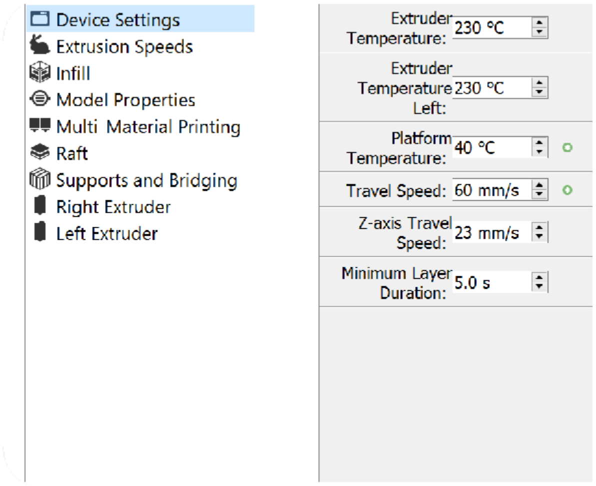
Place the ligamentum flavum mold on the build plate in the orientation shown below. This will optimize the printing process and avoid the need for support material. We recommend using rafts for this part to avoid warping of the bottom layers of the part.

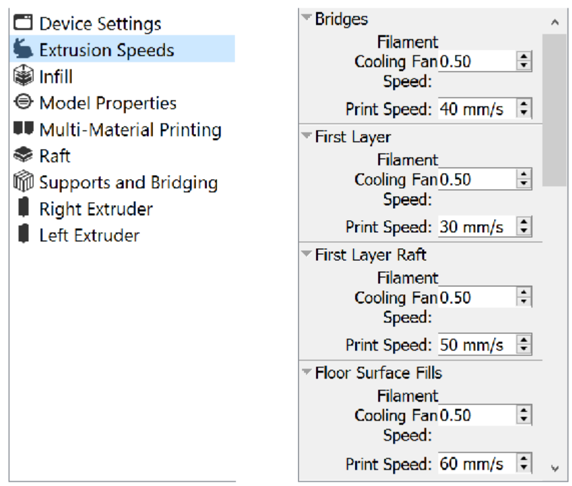


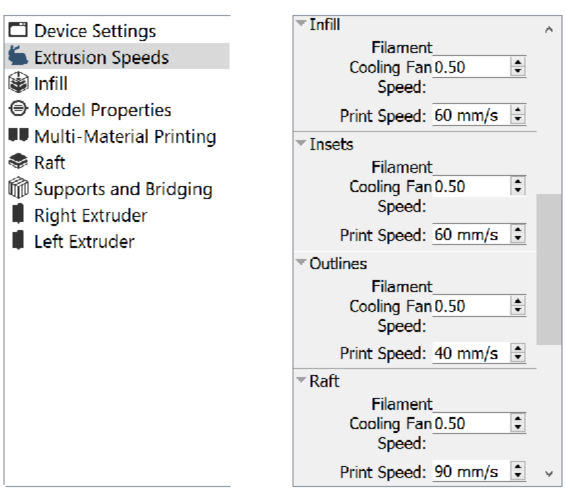
3.2.3 Printer Settings

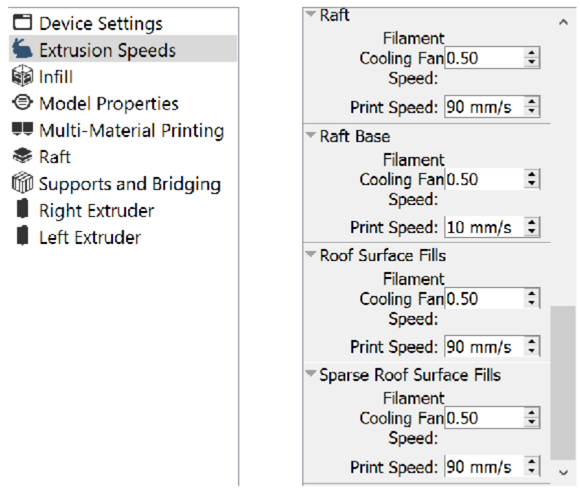
Setting	Value
Nozzle temp	230℃
Infill	15%
Shells	4
Travel Speed	60 mm/s
Platform temp	40℃
Raft	Yes
Supports and Bridging	Select “Support,” “Leaky Connections,” “Align Support,” “Extra Support”, support angle: 40 degrees

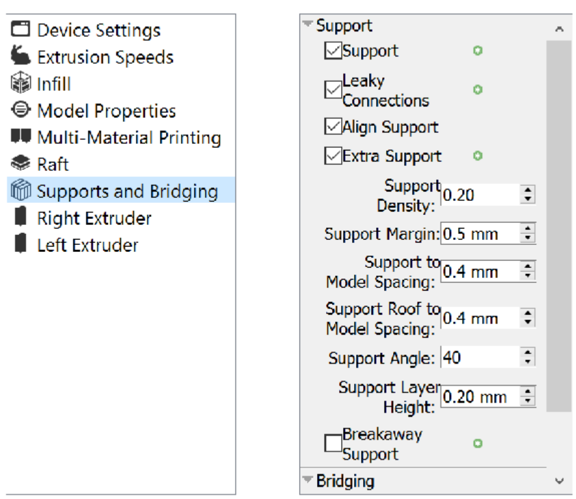
Below are the standard settings we used to achieve successful prints on our 3D-printer. These settings were determined through an iterative process of trial and error on one particular printer. However, these settings should not be regarded as the only true way of attaining successful prints. If, based on your prior experience with 3D printing, you believe that some of the settings should be changed from those shown in the figures below, feel free to do so. It is not uncommon to have to troubleshoot 3D printing of complex objects.


Device Settings
Extrusion Speeds
Infill
Model Properties
Multi Material Printing
Raft
Supports and Bridging
Right Extruder
Left Extruder
Extruder Temperature: 230 °C
Extruder Temperature Left: 230 °C
Platform Temperature: 40 °C
Travel Speed: 60 mm/s
Z-axis Travel Speed: 23 mm/s
Minimum Layer Duration: 5.0 s


Device Settings
Extrusion Speeds
Infill
Model Properties
Multi-Material Printing
Raft
Supports and Bridging
Right Extruder
Left Extruder
Bridges
Filament Cooling Fan Speed: 0.50
Print Speed: 40 mm/s
First Layer
Filament Cooling Fan Speed: 0.50
Print Speed: 30 mm/s
First Layer Raft
Filament Cooling Fan Speed: 0.50
Print Speed: 50 mm/s
Floor Surface Fills
Filament Cooling Fan Speed: 0.50
Print Speed: 60 mm/s


Device Settings
Extrusion Speeds
Infill
Model Properties
Multi-Material Printing
Raft
Supports and Bridging
Right Extruder
Left Extruder
Infill
Filament Cooling Fan Speed: 0.50
Print Speed: 60 mm/s
Insets
Filament Cooling Fan Speed: 0.50
Print Speed: 60 mm/s
Outlines
Filament Cooling Fan Speed: 0.50
Print Speed: 40 mm/s
Raft
Filament Cooling Fan Speed: 0.50
Print Speed: 90 mm/s


Device Settings
Extrusion Speeds
Infill
Model Properties
Multi-Material Printing
Raft
Supports and Bridging
Right Extruder
Left Extruder
Raft
Filament Cooling Fan Speed: 0.50
Print Speed: 90 mm/s
Raft Base
Filament Cooling Fan Speed: 0.50
Print Speed: 10 mm/s
Roof Surface Fills
Filament Cooling Fan Speed: 0.50
Print Speed: 90 mm/s
Sparse Roof Surface Fills
Filament Cooling Fan Speed: 0.50
Print Speed: 90 mm/s


Device Settings
Extrusion Speeds
Infill
Model Properties
Multi-Material Printing
Raft
Supports and Bridging
Right Extruder
Left Extruder
Support
Support
Leaky Connections
Align Support
Extra Support
Support Density: 0.20
Support Margin: 0.5 mm
Support to Model Spacing: 0.4 mm
Support Roof to Model Spacing: 0.4 mm
Support Angle: 40
Support Layer Height: 0.20 mm
Breakaway Support
Bridging

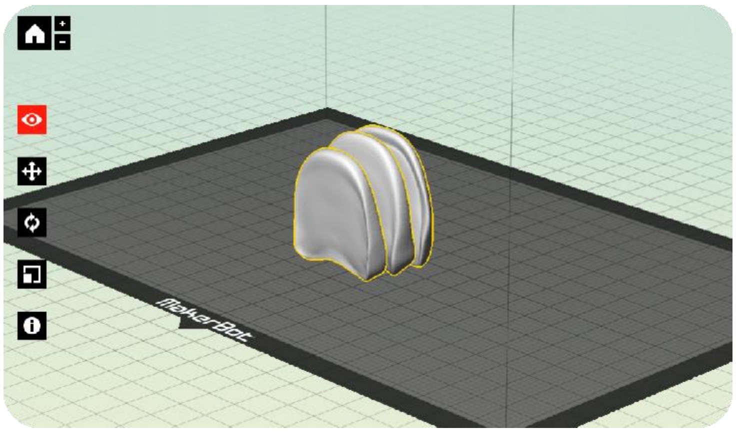
3.3 TPU Parts

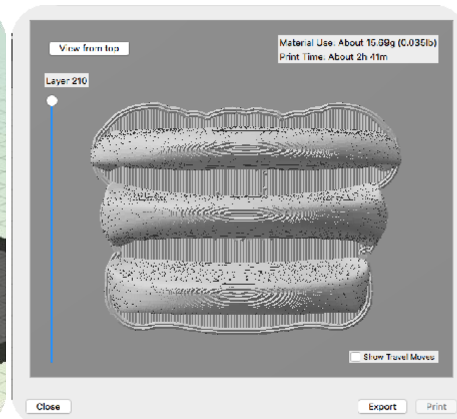
3.3.1 Part Placement

DISCS

If you have not printed with TPU before, try a small test print first.

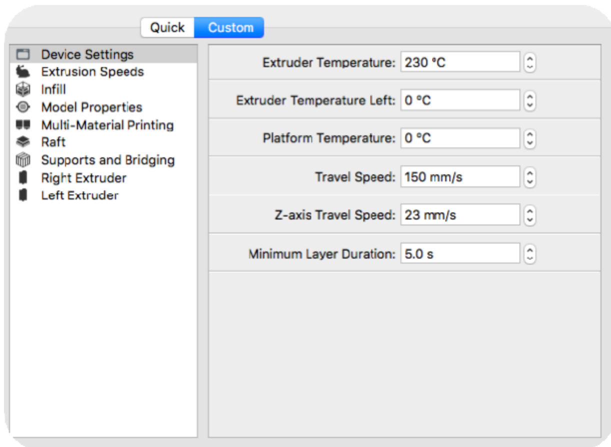
The following figures show the orientation of the discs on the build plate.

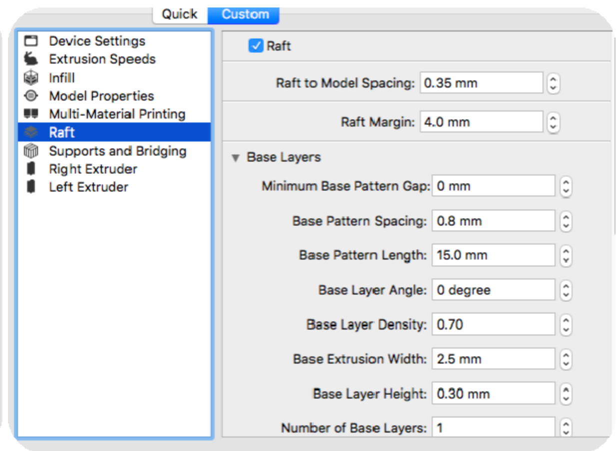


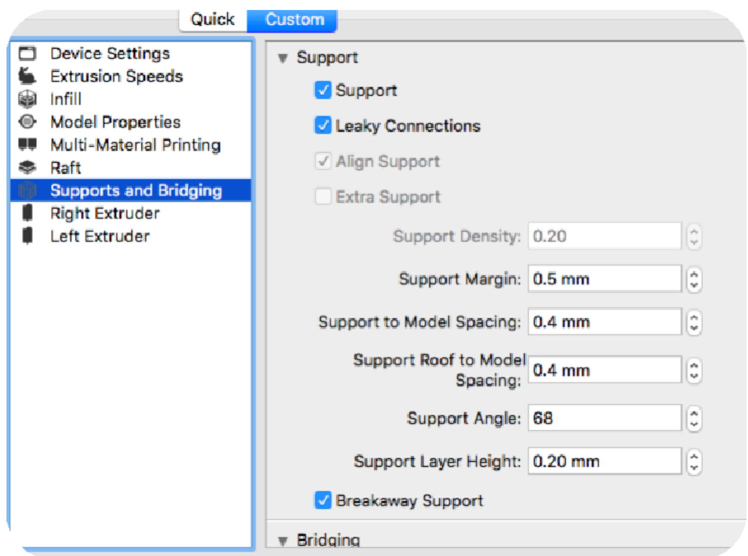


3.3.2 Printer Settings

Setting	Value
Nozzle Temp	230°C
Infill	15%
Travel Speed	150 mm/s

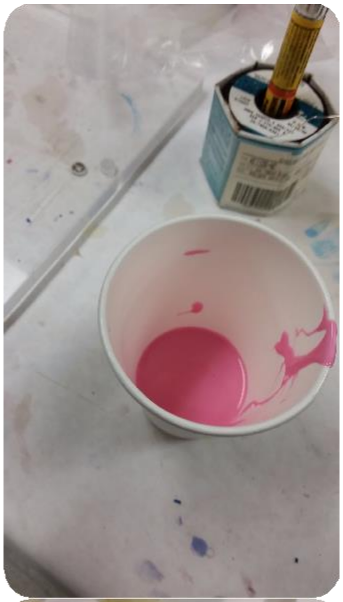






3.4 Ligamentum Flavum

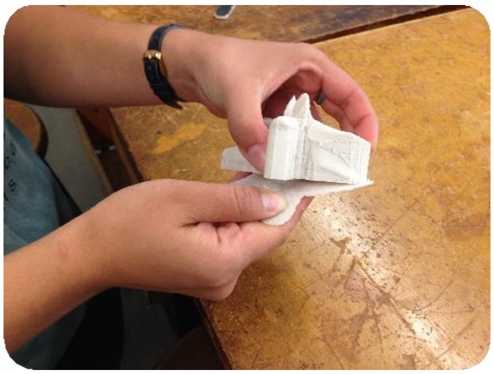
For this, you will need a silicone rubber moldable material, Oomoo. It comes in a kit, containing two buckets of blue and pink compounds. First, you will need to mix both of them in a container of a desired size (we used a regular plastic cup) in the 1:1 ratio by volume. We suggest using syringes to draw the compounds from their corresponding buckets. *Make sure to use different syringes for each compound*.



3.5 ASSEMBLY

3.5.1 Discs and Vertebrae

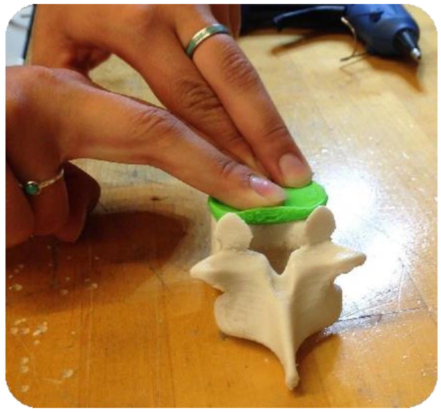
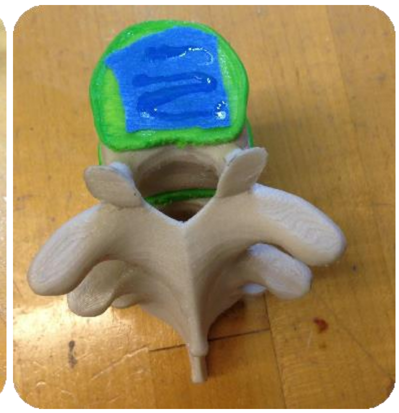
First, clean the 3D-printed vertebrae by removing unnecessary PLA material- rafts and supports. Rafts should come off in one piece. We recommend using pliers and wire cutters to remove the supports.



Smooth each part using file and soldering tools. Make sure to clean the tip of the soldering gun often. We also recommend using sand paper of different grit number to smooth each part as much as possible. Use the same technique for the discs. ***Do not*** *use soldering iron on TPU parts*.

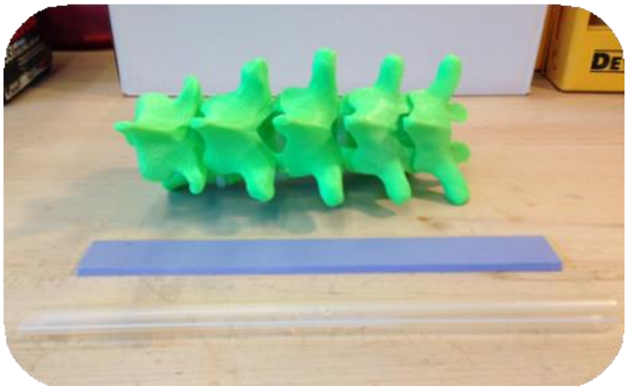
Assemble the vertebrae and discs into a spinal column using Epoxy. It is helpful to roughen surfaces with sand paper before gluing.

In this step, it is very important to ensure the proper alignment of each vertebrae to increase the accuracy of the model.


3.5.2 Inserting the Ligamentum Flavum

Secure the Ligamentum Flavum to the bubble tea straw with duct tape. Trim to appropriate length for the model. Seal the ends of the straw with glue or wax. Slide ligament into the vertebral canal.



3.5.3 Preparing the Base

Base can be made of plywood or medium density fiberboard using a laser cutter. Cut a disc that is ½" thick and 6" diameter.

Drill a hole through the center of the base. Make sure that this is straight. If available, use a drill press. Screw the screw all of the way through the center of the base. Drill a matching hole in the center of the bottom surface of T11. Attach the model to the base.

3.5.4 Soft Tissue Gelatin Mold

For the gelatin mold, we used a 2.25-quart plastic pitcher. We trimmed the top off of it so that it had the following dimensions: height 7 and 1/8 inches, top diameter 5 inches, bottom diameter 4 and ¼ inches. This can be done with a heavy scissors or soldering iron.

We then followed an instructional video on how to make ballistic gel. For our gel we used 60 oz. of tepid tap water (90-100 degrees) and 5 oz. of Knox Gelatin. It is best to place all of the water in a receptacle first and then slowly pour in the gelatin while continuously stirring to get all of the gelatin to mix. Any undissolved gelatin and air bubbles will float to the top and can be easily skimmed off.

The pitcher is prepared with a light coating of olive oil (PAM is too slippery). The liquid gel is poured into the pitcher. The spinal model and base are inverted and placed in the liquid gel with the base resting on top of the pitcher. The base is weighted to keep the model from floating up in the gel.

The model should be placed in the refrigerator for 12 hours to cure.


A BETTER
ROOFING
AA WOOD'S
Tree Service


ORGANIC
VALLEY
Nancy's

When you are ready to use the model, release it from the mold. Usually this simply requires taking it out of the refrigerator and letting it warm to room temperature. Then it will slip out of the mold. Warming it with a hairdryer will speed up the process.

4.0 USING THE MODEL

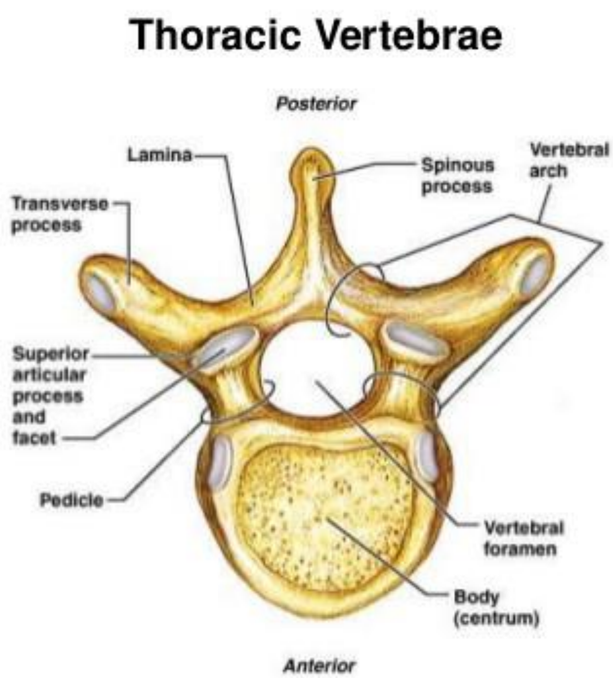
The model includes thoracic vertebrae from T7 to T11. This allows practice of a variety of approaches for epidural placement.

In this model, you can see the vertebrae and Ligamentum Flavum. Although, the technique for placing an epidural in a patient is "blind", you don't have to learn it blind. Seeing your needle tip as you change direction can help you to learn the geometry of needle placement visually as well as tactilely.

Additional supplies needed are a standard 17 gauge/9cm epidural needle and a standard epidural 10ml loss of resistance syringe.

Clamp or Velcro the model to a suitable work surface. Palpate or view spinous processes and choose the level where you would like to place epidural. Since the spinous processes are at a steeper angle and more overlapped in the superior region than they are in the inferior region, your approach will be slightly different depending on which level you choose.

For simulated placement of an epidural at the T7T8 level, find the T7 spinous process. Place your needle tip at a point 1cm lateral to the most prominent part of the spinous process and at a 90-degree angle to the skin. Advance needle until contacting hard lamina. Note depth of needle. Withdraw needle tip to just below skin and redirect needle approximately 20 degrees medial and 20 degrees cephalad (toward the head) and attempt to “walk” needle off of the lamina and into the firm Ligamentum Flavum. If you are still hitting hard bone with your needle tip, pull back and redirect 2 to 3 degrees more medial and cephalad. Continue this pattern until you secure needle tip in Ligamentum Flavum.



Remove stylet from needle and hook up 10 ml syringe. Make sure that there is 3 to 4 ml of air in the syringe. We will be practicing a “loss of resistance to air” technique (In a patient, you may use a “loss of resistance to saline” technique). Advance needle at a slow steady rate with continuous pressure on the syringe plunger. When you “pop” through the Ligamentum Flavum and into the epidural space you will feel a brisk loss of resistance to air. Remember, this is a simulation and the feel in an actual patient will be somewhat different. Stop here. This is where you would thread a continuous epidural catheter.

For epidural placement at the T9T10 level, the procedure will be the same, but will require less cephalad angulation of the needle.

Enjoy practicing with this model! Use it in any way that you like to satisfy your curiosity about epidurals and their placement!

5.0 REPLACING LIGAMENTUM FLAVUM & SOFT TISSUE

After multiple needle passes (we have found this to be about 50), the Ligamentum Flavum and the gel soft tissue will need to be replaced. The existing gel can be removed from the model and composted.

The ligament can be pulled out of the spinal canal and discarded. The model should be rinsed thoroughly in warm water to remove any remaining gel. The ligament and gel can be replaced and this model can be reused indefinitely.

6.0 REFERENCES

1. Kopacz D, Neal J, Pollock J. “The regional anesthesia “learning curve”: what is the minimum number of epidural and spinal blocks to reach consistency?” Reg Anesth, 1996;21:182-190.
2. Friedman Z, Siddiqui N, Katznelson R, Devito I, Bould M, Naik V. “Clinical Impact of Epidural Anesthesia Simulation on Short-and Long-term Learning Curve.” Reg Anesth Pain Med, 2009;34:229-232.
3. An N, “Human Spine.” *GrabCAD - CAD Library*, https://grabcad.com/library/human-spine-1.