TIPS, TRICKS & TECHNIQUES

Make Your Own Working Models of Heart Valves!

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Abstract

Heart valves play a vital role in efficient circulation of the blood, and the details of their physical structure are related crucially to their function. However, it can be challenging for the learner to make the mental connection between anatomical structures of valves and the changing pressure gradients that the valves experience and come to an understanding of valve function. Making your own simple, inexpensive working models allows your students to visualize valve action quickly and easily, and to predict effects on function if valve structure were altered. A link to a video showing use and construction of the working valve models is given.

Key Words: *Heart valve; model; active learning.*

Pushed open or closed by the pressure of the blood acting on them, valves in the circulatory system promote the efficient forward flow of blood. Contraction of the muscular chambers of the heart propels blood into adjacent chambers of the heart or into outflow arteries. The valves inside the heart and at the bases of the aorta and pulmonary trunk prevent blood from going back into an atrium or ventricle when it relaxes. For example, as pressure within the contracting left ventricle rises above that in the aorta, this pushes the aortic valve open, sending blood forward into the aorta. As the ventricle relaxes, pressure within it decreases, and if there were no valve present, the blood the ventricle had just pumped out would likely flow right back into the ventricle. However, because the higher pressure of blood within the elastically recoiling aorta pushes the valve closed, the blood flows forward within the aorta and toward the body cells. Strong, thin, flexible, and smooth, the leaflets of our heart valves typically work efficiently for us for years without problems.

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Textbooks, anatomical models, and dissections of preserved specimens don't help much in visualizing and understanding how these valves actually work, and films made from inside the heart typically provide a brief glimpse from a confusing orientation. Hands-on learning supports understanding, builds confidence, and makes science more accessible to all learners (Goodman et al., 2006). Working models such as the lung model built from a bottle, balloons, tubing, and a y-connector (Bailey, 2013) can help students learn. I have used references such as *Gray's Anatomy* (Standring, 2008) and my own observations from dissection of both fresh and preserved specimens to develop simple working valve models that operate using exhaled air instead of blood. I have used versions of these working valve models successfully for 25 years in teaching anatomy and physiology.

○ Objectives

- To make working models of heart valves using inexpensive materials and your own creativity
- To show the mechanical nature of heart valves and combat the common misconception that chordae tendineae help open atrioventricular valves
- To engage students – when people try these models out, they see immediately for themselves how the valves work
- To improve students' understanding and appreciation of the work of valves, especially if students make their own models and tinker with them

The models are constructed of inexpensive, common materials that work well, and the procedures are simple, but there are probably many different approaches. I use these working models for demonstration. I also like to give students assorted materials to work with, sample valve models to observe, and the idea that the valves should allow flow in one direction and stop it in the other direction. I let them be creative in building their own model, either individually or in working groups. Please experiment!

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With the assistance of the Seattle University Media Production Center, I have also made available two YouTube videos to demonstrate how these valves work and how to build the models (Part 1: http://youtu.be/H4q1u2aCbjo; Part 2: http://youtu.be/TUUrcK-8pnc).

○ Materials

- Plastic transparency sheets (about 216 × 279 mm)
- Scissors
- Transparent tape (13 mm wide)
- Double-sided tape
- Thin, flexible sheets such as lab wipes, tissue paper, thin grocery produce bags, or lightweight disposable vinyl gloves
- Spools of sewing thread
- Rulers
- Marking pens
- Single-hole paper punch
- Facial tissue
- Quadrille ruled paper (helps with alignments)
- Other materials? Be creative!

It takes only about 15–20 minutes to make one of these valve models.

○ Semilunar Valve (Easiest)

These valves have pocket-like leaflets that are pushed flat against the wall of the blood vessel by blood pressing harder against them from one direction (Figure 1A). Blood flowing back the other way fills up the pockets, which bulge against each other to close the valve. This maintains forward flow in the blood vessel.

Mark a Guideline for Valve Placement

Use a marking pen and ruler to draw a straight line across the width of a transparency sheet about halfway between the ends.

Cut the Valve Leaflets

Cut disposable gloves or lightweight produce bags into three valve leaflet pieces about 70 mm long and 80 mm wide, in the shape of pockets with a straight top and a curved bottom.

Place the Valve Leaflets

Fold under 5 mm along the left edge of one leaflet piece, and align the folded edge with the left edge of the transparency sheet so that the straight top of the leaflet lies along the line you drew across the transparency sheet (Figure 1B). Tape the folded edge down securely next to the edge of the transparency sheet with 2–5 mm of tape extending up beyond the flap. Place another strip of tape in the same position along the right edge of the same leaflet. Fold under that edge and gently flatten out the leaflet along the guideline, pressing the right edge of the leaflet to the transparency. Push under ~5 mm along the bottom edge of the leaflet and tape this edge to the transparency. The finished leaflet will resemble the hip pocket on jeans. Repeat the process for the second and third leaflets, setting them side by side. Getting them very close to each other prevents leaks. Leave ~10 mm between the taped edge of the third leaflet and the right edge of the transparency so that you can roll up the sheet and fasten it securely.

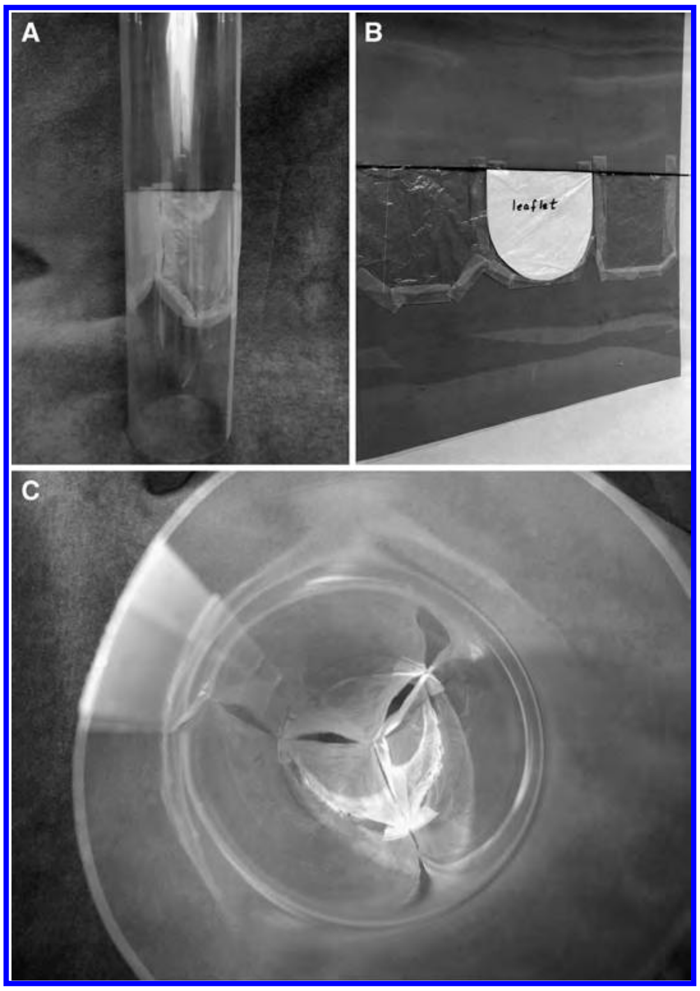

Figure 1. Semilunar valve model. (A) Completed model. (B) Model ready to roll up. (C) View inside model down to closed valve.

Roll up Your Artery

Gently roll up the transparency along its length, overlapping the two long edges and bringing the left edge of the first leaflet right up against the right edge of the third leaflet. Tape the outside edge of the tube at that level to hold the valve aligned and try out your model before you tape the rest of the tube.

Test Your Model

Blowing forcefully into the tube at one end should flatten the valve leaflets against the wall of the tube, allowing the air to flow along the length of the tube and out the other end. Blowing forcefully into the tube at the opposite end fills the leaflets ("pockets"), closing off the passageway (Figure 1C). When you are satisfied with your valve, tape up the rest of the length of the tube so that it can be easily passed from person to person to try out. Using transparency sheets makes it possible for other people to see what is happening when someone blows into the tube.

Ask: *How is this related to the way the aortic valve, pulmonary valve, or valves in veins work in our bodies?*

Ask: *If you are interested in pathologies that involve valves, could you make a model that would demonstrate aortic stenosis or insufficiency? How would it differ from the "normal" model?*

○ Aortic Semilunar Valve

The wall of the aorta has openings to coronary arteries right behind two of the three leaflets of the aortic valve (Figure 2). This model shows flow into a coronary artery when the valve is being pushed shut by blood flow back toward the relaxing heart.

Mark the guideline as for the basic semilunar valve.

Make the Opening to a Coronary Artery

Mark a spot ~30 mm down from the guideline and ~35 mm from the left edge of the transparency sheet (so that it will be covered by the first leaflet when the leaflet is flat against the wall). Punch a hole through the sheet at this spot. You can draw a circle around the hole with a marking pen to make it easy for people to see.

Continue with placement of leaflets, rolling up, and trying out your valve model as before. You may be able to feel air flowing out through the hole in the artery wall when you blow the valve shut, but make it easy to see by cutting a small flap (~60 mm long) of single-thickness facial tissue and taping one end to the outside of the tube ~15 mm above the hole. When no air is flowing through the hole, the flap lies against the tube wall, but air flowing out of the hole makes the tissue flip out, which is easy for everyone to see.

○ Atrioventricular Valve

The atrioventricular valve leaflets (Figure 3A) are like sheets. With the string-like chordae tendineae attached to the atrioventricular valve leaflets at one end and to the papillary muscle of the ventricle wall at the other end, the whole setup looks rather like a parachute. The chordae tendineae keep the valve leaflets from inverting into the atria when ventricular contraction drives up the pressure.

Mark the Guideline for Valve Placement

With a marking pen and ruler, draw a straight line across the width of the transparency ~90 mm from one end of the sheet.

Cut the Leaflets

Cut a sheet of lab wipe in half lengthwise so that you have a piece about 55 × 210 mm. Any very flexible but strong material should work for this.

Place the Valve Leaflets

Lay a long straight edge of the lab wipe along the top of the line on the transparency so that one short edge is even with the left edge of the transparency sheet and the leaflet is aimed up to the far end of the transparency. If you stretch the valve flap slightly as you tape it down so that it reaches about 2–3 mm farther toward the right end of the line, it will fit inside the tube more smoothly when you roll it up. Trim the leaflet so that it ends ~10 mm from the right edge of

Figure 2. Completed aortic valve model with opening to coronary artery.

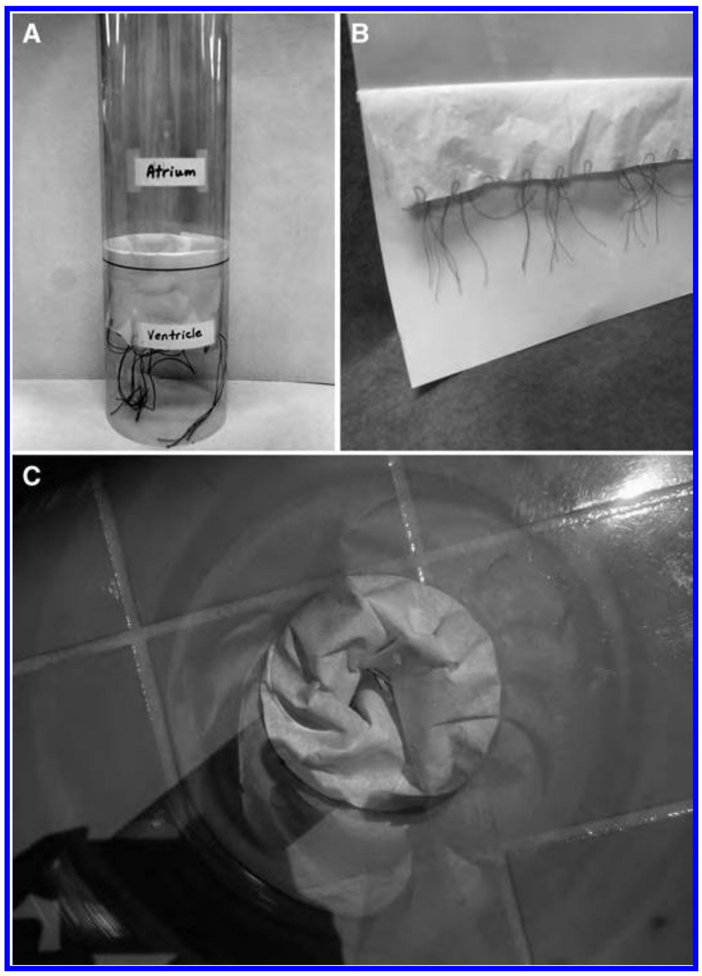

Figure 3. Atrioventricular valve model. (A) Completed model, open to flow. (B) Model ready to roll up. (C) View inside model down to closed valve.

the transparency. Leave ~1 cm at the right end of the leaflet untaped so that you'll be able to join it to the left edge of the valve when you roll up the transparency.

Add Chordae Tendineae

Cut 7–9 pieces of sewing thread ~200 mm long. Gently fold the leaflet down from the taped edge so that the free edge is closer to the lower end of the transparency sheet. Fold a piece of thread in half and use a small piece of tape to fasten the fold onto the leaflet 3–5 mm up from the long free edge and ~20 mm from the left end. Repeat with the other pieces of thread, spacing them evenly along the length of the valve flap (Figure 3B). Getting the chordae tendineae the right length is a matter of trial and error, but you can start by using small (about 5 × 30 mm) strips of transparent tape to stick them down to the transparency sheet ~50 mm down from where the leaflet attaches to the guideline and so that the tails of the threads extend ~50 mm beyond the tape. Test the length of your chordae tendineae by gently lifting up under the leaflet. The attached threads should keep the leaflet edge from lifting up beyond the guideline. Try rolling up the tube so that the short edges of the leaflet meet, and blow hard through the tube to check the valve action. If you need to adjust the thread lengths, pull gently on the threads either just above the tape (to loosen) or just below it (to tighten).

Join Short Edges of the Leaflet and Roll up the Tube

Place a thin (~10 mm wide) strip of double-sided tape on the short edge at the right end of the leaflet, gently bend the transparency lengthways so that you can overlap that edge with the left end of the leaflet, and squeeze gently to stick them together to form a ring of tissue. Overlap one long edge of the transparency with the other to roll it up so that the valve is inside the tube. Tape the outside of the tube at the level of the valve and give it a test blow. If it seems to be working well, tape the rest of the long edge of the transparency. If the valve is tending to invert, you can reach up inside the tube to tighten the threads. Blowing in one direction should close the valve (Figure 3C).

Ask: *What are the chordae tendineae actually doing? Are they helping open the valve or close it? What would happen if we left them out?* Make a model valve without threads and test it. (It will invert perfectly – which wouldn't prevent backflow within the heart.)

Ask: *How could we build the model differently to show mitral stenosis or insufficiency?*

Ask: *How are all these valve structures similar to the ones we find in and near the heart? How would they be influenced by contraction and relaxation of the heart muscle, and by elastic recoil of the aorta and pulmonary trunk, which are not built into our model? How do artificial valves designed by bioengineers deal with the challenge of providing efficient one-way flow?*

Pibarot and Dumesnil (2009) discuss and illustrate both biologically based and wholly artificial valve replacements for people whose heart valves are diseased. Parts of this article are more technically complex than may suit your objectives, but they consider mechanical factors that can be related to our working valve models and discuss clotting problems and immune reactions that may intrigue your students.

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