

Young Scientist Program: Anatomy Teaching Team



Module 2: **Lung Function + Physics of Breathing** **“How does air actually get into our lungs?”**

A.) Introduction

Everyone knows that breathing is essential to life. Every person on the planet has air going into and out of their lungs multiple times per minute, and remarkably this process keeps us all alive. From the previous lesson we know that the most important function of breathing is gas exchange. Air coming into our lungs through the respiratory tract has high levels of oxygen and low level of carbon dioxide. Therefore, inside the lungs (specifically in alveoli) oxygen can diffuse into the blood, which will then be circulated throughout the body to keep cells/tissues alive, while the carbon dioxide in the blood can diffuse out into the air in the aveoli, where it will then be expelled from the body through exhalation. The exchange of gasses that occur in the microscopic sacs in the lungs is very important in sustaining life. Not only does it allow our bodies to take in oxygen, needed for all of our cells and tissue to function and survive, but it also allows us to get rid of waste gasses (such as CO₂), which otherwise would disrupt the delicate chemical balance of our body.

In the previous lesson we also talked about the path that air takes as it moves from our mouth/nose into our lungs. Yet why does air move into and out of our lungs when we breathe in and out? What are the forces or factors involved in the movement of air and how is our body designed to control the movement of air in and out of our lungs? This lesson will answer some of these questions and describe how the various components of the thoracic cage/cavity contribute to our ability to breathe.

B.) Building a Model of the Respiratory System in the Chest

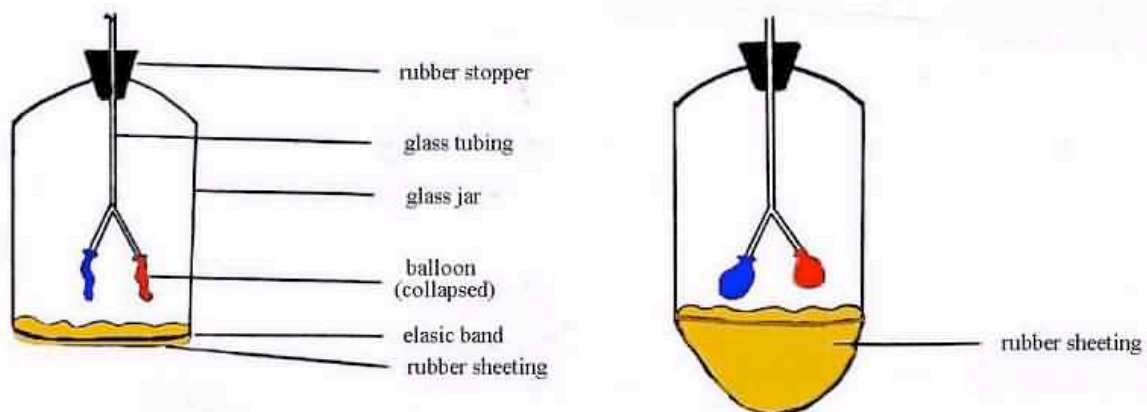
How does air get from our nose/mouth into our lungs? We know from the prior lesson that air moves from our **nose/mouth**, to our **pharynx**, to our **larynx**, to the **trachea**, which then split into many **bronchi** and **bronchioles**, which distribute air throughout the volume of the **lungs** into tiny air-filled sacs known as **alveoli**. Yet why does the air actually move in and out of our lungs along this path? To answer this question we are going to build a model of the respiratory system.

Steps to Building the Model:

1. *Everyone needs one bottle with a cap.* This bottle is going to *represent the rib cage*. The rib cage is a hard structure in your chest that is made up of many

different bones, including your ribs, your sternum, and your vertebral column. Because it is made of interconnected bones it is very hard and stiff. Your heart and lungs sit inside of the rib cage, and therefore the rib cage protects your heart and lungs from damage.

2. *Everyone needs one piece of tubing.* This piece of tubing is going to *represent the pharynx/larynx*, while the opening of the tubing is going to *represent the mouth*. The pharynx/larynx connect the mouth/nose, where the air comes into the body, to the trachea, which distributes the air to the two lungs.
3. *Everyone needs one Y-connector.* This Y-connector is going to *represent the trachea*. The trachea connects the pharynx/larynx with the lungs, and it split into two main bronchi which each carry air to one of the two lungs.
4. *Everyone needs two pink balloons and two zip ties.* The balloons are going to *represent the lungs*. As we talked about before, the lungs are really just big collections of very tiny air sacs, which make it like one big sponge or balloon. Much like a balloon the lungs can inflate and deflate as air moves in and out of them.
5. *Everyone needs one big balloon.* The big balloon represents a big muscle that covers the bottom of our rib cage called the *diaphragm*. Like this muscle, the balloon is very flexible and can stretch or contract, changing the volume of the chest cavity.
6. STEP #1: Attach the plastic tubing to the single end of the Y-connector.
7. STEP #2: Roll up the tubular end of the pink balloons and attach one balloon to each of the split ends of the Y-connector using a zip tie.
8. STEP #3: Insert the tube through the hole in the bottle cap from the inside of the bottle. Position the split in the Y-connector approximately 2-3" below the bottle cap.
9. STEP #4: Hold the tubing steady in the bottle cap and then seal the joint between the tubing and the bottle cap with hot glue. (Provided by the instructor.)
10. STEP #5: Take the large balloon, spread the opening as wide as you can. Next spread the balloon over the open end of the bottle. Make sure that there is a tight seal between the balloon and the bottle.



C.) How the Model Works

Once you have your model constructed you can test it out. When you pull down on the tab of the large balloon, simulating contraction of the diaphragm, the balloons, representing the lungs, should fill with air and expand. This movement simulates a single inspiration. On the other hand, when you release the large balloon (or push the large balloon into the bottle), simulating a relaxation of the diaphragm, the balloons, representing the lungs, should empty out and contract. This movement simulates a single expiration.

So how does the movement of the diaphragm move air into and out of the lungs? Well, when the diaphragm contracts during inspiration (simulated in the model by pulling down on the tab of the large balloon) the volume of the chest cavity (the closed space inside of the bottle) increases since the balloon is now bending “outward”. As the chest cavity is a closed space, and is sealed off completely with the bottle cap and the balloon on either end, no air can move into the chest cavity to fill this sudden increase in volume. Therefore, the number of “air molecules” inside the chest cavity is fixed. Yet, now that the volume of the chest cavity has increased the concentration of gas, or number of “air molecules” per unit volume, has decreased. This therefore causes a decrease in the pressure inside the chest cavity (the closed space inside the bottle). The decrease in pressure inside the chest cavity (the closed space inside the bottle) then causes a difference in pressure between the air inside the lungs (balloons) and in the chest cavity (the closed space inside the bottle). This pressure difference causes the lungs (balloons) to expand along with the chest cavity, again causing a local increase in volume inside the lungs (balloons) which results in a local decrease in pressure inside the lungs (balloons). Yet, given that the lung (balloons) are connected to the environment through the pharynx/larynx (tubing), and that the air outside the body (outside the bottle) is at a higher pressure than the air inside the lungs (balloons), air can rush into the lungs (balloons) to fill the sudden increase in volume.

So overall, the lungs are “connected” [technically coupled] to the chest cavity. As the chest cavity expands upon contraction of the diaphragm the lungs expand causing a pressure difference between the inside of the lungs and outside air which draws air into the lungs during inspiration.

On the other hand, when the diaphragm relaxes during expiration (simulated in the model by releasing the large balloon or pushing the large balloon into the bottle) the volume of the chest cavity will decrease. This will cause a reversal of the situation found during inspiration, in which the pressure inside the chest cavity (the closed space inside the bottle) will increase, causing a decrease in the volume inside the lung (balloons) which will cause an increase in the pressure inside the lungs (balloons), which will then cause a pressure difference between the air in the lungs (balloons) and the air outside the body (outside the bottle) which will force the air out of the lungs (balloons).

So overall as the chest cavity contracts upon relaxation of the diaphragm the lungs contract causing a pressure difference between the inside of the lungs and outside air which forces air out of the lungs during expiration.

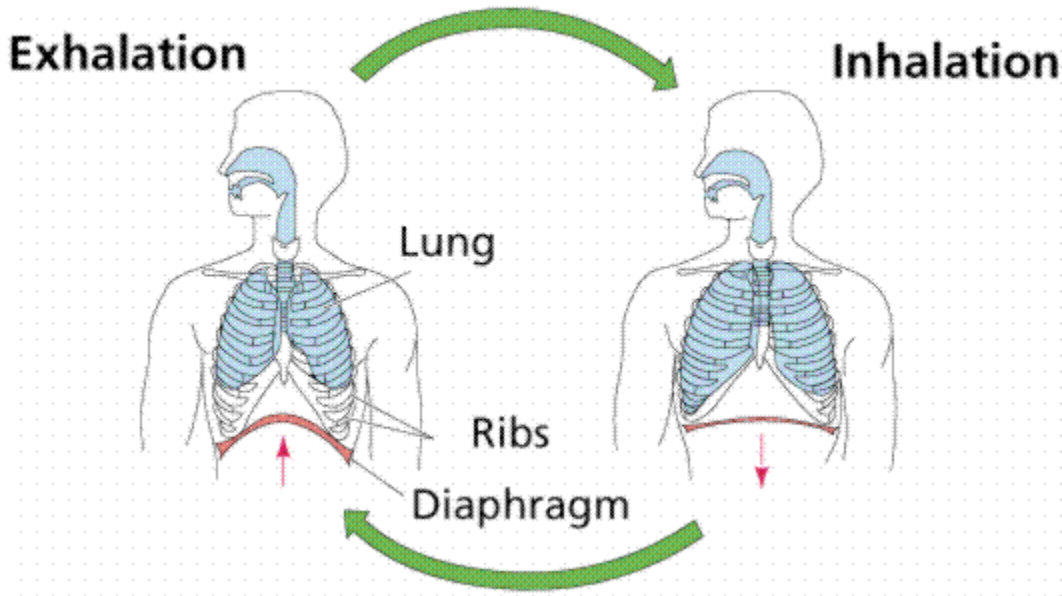
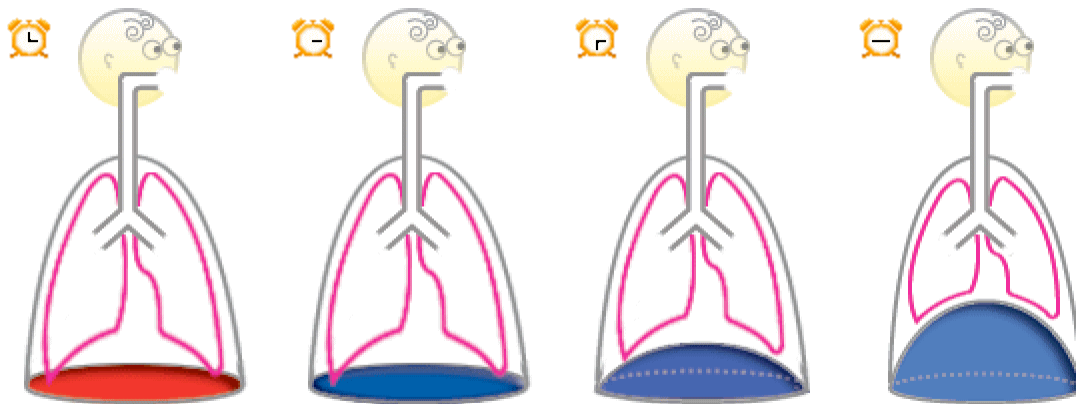
In general, the movement of air in and out of the lungs is controlled by pressure differences between the air inside and outside the lungs, which are generated by the contraction of various muscles in the thorax and the motion of the chest cavity.

Questions to ask:

How could this model be adapted to simulate a condition like asthma? emphysema? a collapsed lung?

In Depth Topics:

Explain how Ideal Gas Law Applies to this Situation ($PV=nRT$),



D.) Differences Between Our Model and the Real Thing

Of course our plastic bottle/balloon model is not a perfect illustration of how breathing occurs in the human body. In actuality the “mechanism” by which breathing occurs in the human body is a bit more complicated. First, the diaphragm is not the only

muscle that controls respiration. In actuality there are a large number of muscles that contribute to expanding and contracting the rib cage during inspiration/expiration. The diaphragm is by far the most important, and largest, of these muscles, but muscles such as the **intercostals** (in between the ribs), the **serratus anterior** (on the side/back of the rib cage), the **sternocleidomastoid** (sides of the neck), the **scalenes** (side of neck), and the **abdominal muscles** also play a part at various times. So if we really wanted a good model we would have to include a lot more balloons on the outside of the bottle.

Second, the rib cage is not a totally fixed structure that does not change shape or flex. Actually, the rib cage can change shape when the various bones comprising its structure articulate at the joints that connect them together. This allows the rib cage to change volume by changing shape, or expanding/contracting, in more than one direction or along more than one axis. So if we really wanted a realistic model of the rib cage we would have to find some type of container/bottle that could flex/bend in multiple directions, and was not as stiff/rigid as our bottle.

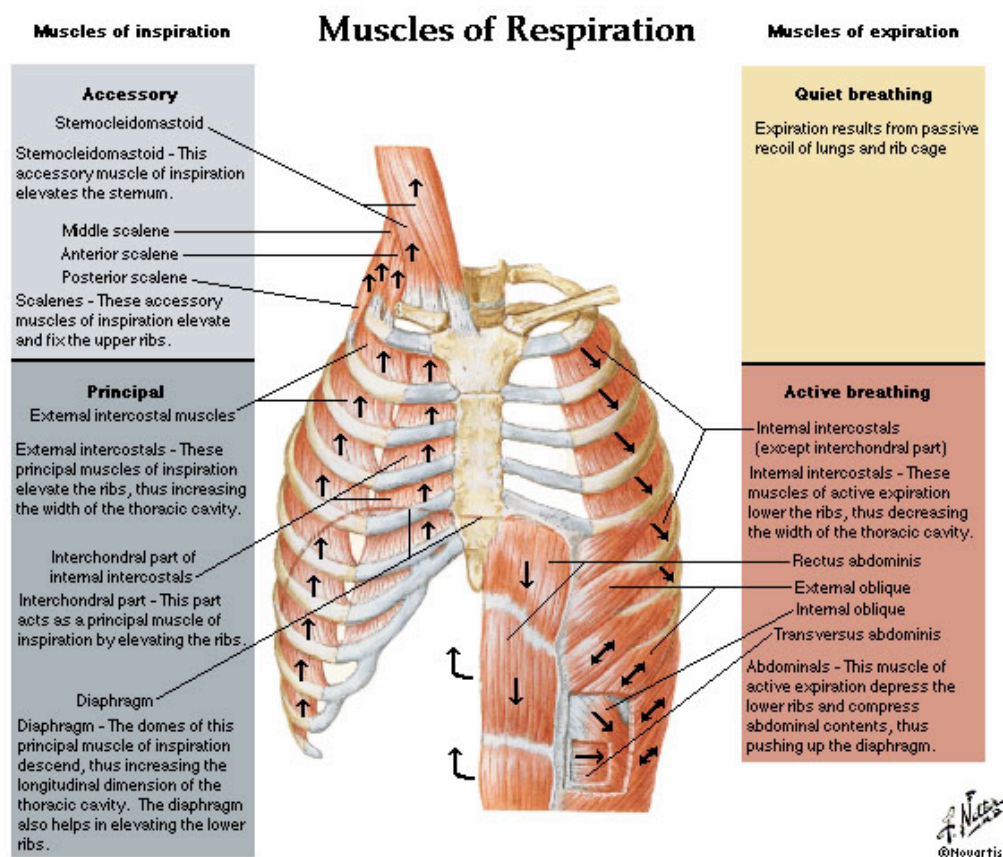
Third, the actual function/action of the diaphragm is a bit different in the human body in comparison to our model. [This pairs up with the second point.] In the human body when the diaphragm contracts during inspiration it actually spreads the rib cage apart (both in the anterior-posterior, and medial-lateral axes), therefore increasing its volume and causing the pressure drop necessary for inspiration. This action, while seeming counterintuitive, is due to the fact that the diaphragm is sort of “draped” over the internal organs of the abdomen, which it uses as a fulcrum of sorts. So, when the diaphragm contracts it actually pulls the lower edges of the rib cage up and out, thereby increasing the volume in the rib cage. This motion is can be described as a “bucket-handle motion” because the lower edge of the rib cage swings out in a fix manner, just like a bucket handle swings on its pivots. So if we really wanted to make an accurate model we would need a bottle that was hinged or could move/expand in along these two axes.

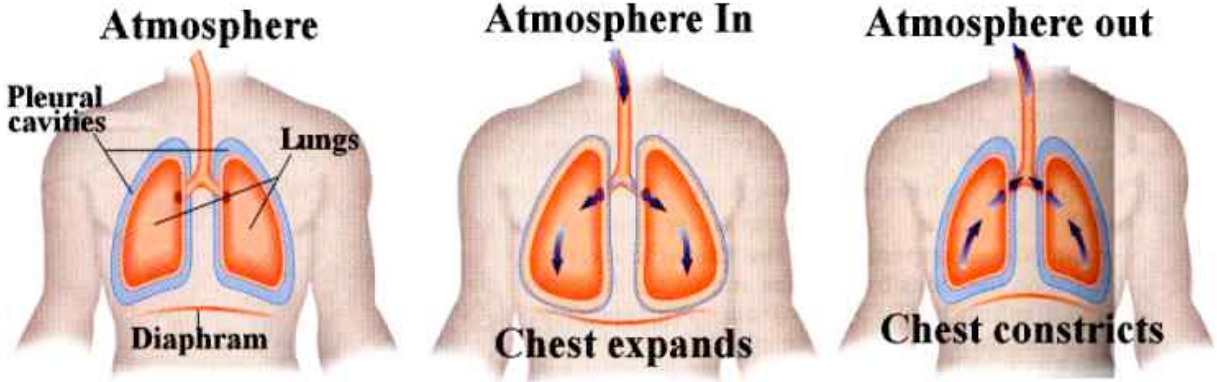
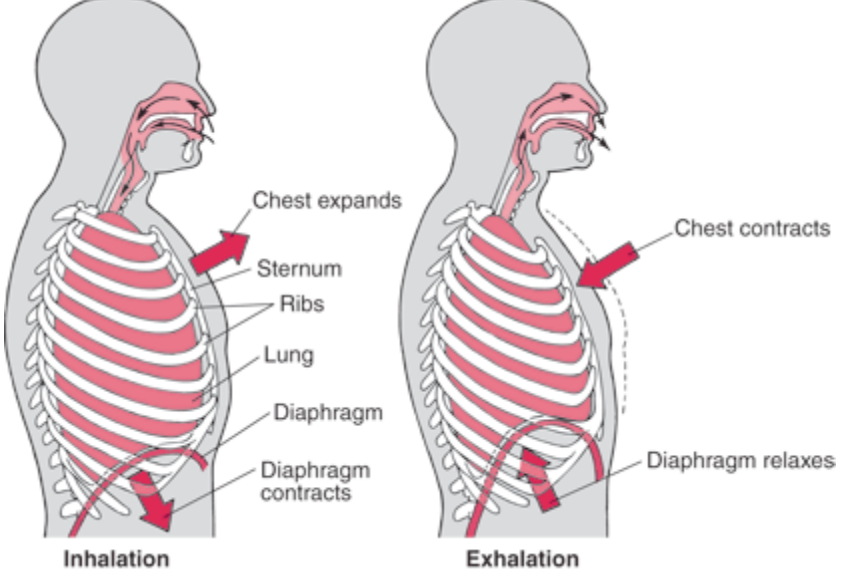
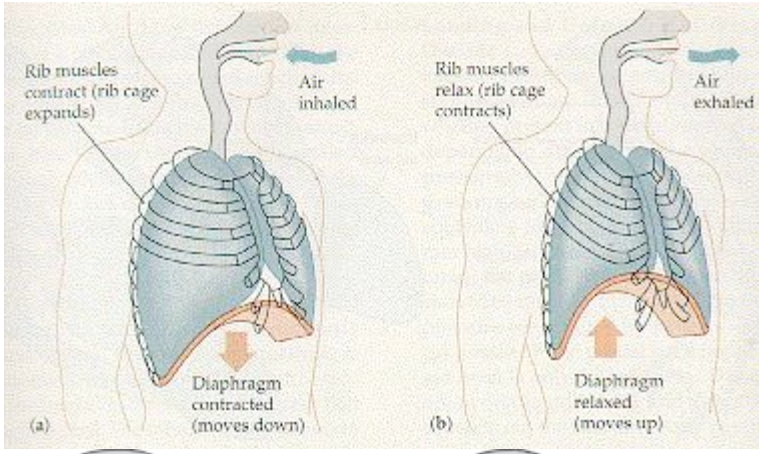
Third, we brief concluded (based on our model) that the lungs are “connected” or “coupled” to the movement of the rib cage. [As the rib cage expands, so do the lungs, etc.] In actuality there is an anatomical feature that explains this coupling. Between the lungs and the inside of the rib cage (known as the pleura) is a thin layer of liquid known as **pleural fluid**. This layer of fluid causes the lungs to “stick” to the inside surface of the rib cage through surface tension, and therefore causes the lungs to move in and out along with the rib cage. So, if we wanted to improve our model we would actually need some fluid/adhesive to connect the lungs (balloons) with the inner wall of the rib cage (bottle).

Fourth, while normal inspiration is an “active” process, meaning that it is caused by contraction of a set of muscle (primarily the diaphragm), normal expiration (when breathing normally) is actually a “passive” process and does not require and muscle contraction at all to occur. This phenomenon is due to the fact that as the rib cage is “spread out” with the contraction of the diaphragm during inspiration, the tissue inside the rub cage acts like a spring and wants to pull the rib cage back to its resting position/volume. Therefore, even if no muscles contract, the rib cage will naturally

contract after inspiration is over, causing air to exit the lungs. When you think about it this is a very efficient way to breathe, as it limits the amount of energy you need to use during every breathing cycle. Our model does exhibit this property a bit, as the large balloon representing the diaphragm does have some elasticity to it. But in a more accurate model the actual rib cage (bottle) would have some type of elastic quality as well that would allow it to retract after being filled with air.

Furthermore, this active/passive nature, along with the specific muscles utilized for breathing, can change with respiratory rate and level of exertion. As we mentioned before, normal inspiration generally only involves the diaphragm, but under great exertion (such as after a marathon or during some respiratory diseases) the **intercostals**, **serratus anterior**, **sternocleidomastoid**, and **scalene muscles** will all assist in expanding the rib cage with each breath. Similarly, normal expiration is generally a passive process, but under great exertion (such as after a marathon or during some respiratory diseases) expiration can become an active process and involve many muscle groups such as the **intercostal** and **abdominal muscles**.







The diaphragm
is shaped
like a parachute



ADAM.