A simple model to demonstrate the balance of forces at functional residual capacity

Praghalathan Kanthakumar and Vinay Oommen
Department of Physiology, Christian Medical College, Vellore, Tamil Nadu, India
Submitted 9 February 2012; accepted in final form 4 April 2012

Numerous models have been constructed to aid teaching respiratory mechanics. A simple model using a syringe and a water-filled bottle has been described by Thomas Sherman to explain inspiration and expiration (4). The elastic recoil of the chest wall and lungs has been described using a coat hanger (1) or by using rods and rubber bands (3). A more complex two-component model has also been described by Kuebler et al. (2). The model described below is a modification of the classical balloon and jar experiment that is simple to construct and explains the balance of forces at functional residual capacity (FRC). The model also uses the elastic nature of the materials to represent the elastic nature of the lung and chest wall.

Materials and Methods

Materials required. The following materials were used in the model: a transparent plastic bottle, a thick latex rubber glove, a balloon, “blu-tack” or bubble gum, instant glue, a metal hook, and a small piece of wood.

Construction. The bottom of the plastic bottle was cut off, and the edges were smoothened to avoid sharp edges. The palm portion of a latex glove was cut out to provide a flat rubber piece. A thick rubber glove was chosen so that it could adequately support the elastic recoil of the balloon. (Thinner gloves may permit the balloon to collapse completely.) This rubber piece was stretched taut over the bottom of the bottle and carefully glued on to the bottle with the help of instant glue. A balloon was placed inside the bottle, and the mouth of the balloon was placed over the mouth of the bottle. In this configuration, it would be impossible to inflate the balloon, and to do so, a small hole was made in the bottle that could be covered with any putty-like material, such as blu-tack or bubble gum. This served as a vent. To facilitate pulling the rubber sheet, a small wooden piece was pasted on its inner surface, and a hook attached to this piece from the outside. Sufficient instant glue was spread uniformly to ensure that all edges were air tight. Parallel dotted lines were drawn on the balloon before it was inflated. This enabled clear visualization of the changes in the balloon volume. The final assembly was as shown in Fig. 1.

Presentation of the model. The model was presented to 60 students during a lecture session. The students had already been taught the theoretical aspects of ventilation in previous sessions. The model was presented to the students as a series of questions to increase student interactions.

At the onset, the structure of the model was explained, and the students were asked to identify what each component stood for. The balloon stood for the lungs, and the rubber sheet stood for the combined elasticity of the chest wall and diaphragm.

Students were then told that the balloon would be inflated with the vent hole opened, and then the vent hole would be plugged. They were asked what would happen when the inflating pressure was released and the balloon was left open to the atmosphere. Some students said that the balloon would collapse. Others said that the rubber sheet would be sucked in. However, when the inflating pressure was released, both indeed occurred. The size of the balloon reduced and the rubber sheet was sucked in until the inward collapse of the balloon was balanced by the outward recoil of the rubber sheet.

Students were then asked which lung volume or capacity this represented, and the answer was readily obtained that this was FRC (Fig. 2A).

Fig. 1. A: the final assembled model, which replicates the forces in action at functional residual capacity (FRC) of the lungs. The vent is plugged after inflating the balloon. The inward recoil of the balloon is balanced by the outward recoil of the rubber sheet. Note in B: the rubber sheet is sucked in due to the negative pressure in the bottle.
It was then easy to explain how inspiration was active. Pulling on the hook flattened the rubber sheet and expanded the balloon. On releasing the hook, the rubber sheet returned quickly to the equilibrium position, showing that normal expiration was passive (Fig. 2B). The rubber sheet was then pressed further inward to demonstrate that forced expiration beyond FRC was an active process, and the subsequent return to FRC was passive (Fig. 2C). (For a better visualization of the volume change during inspiration and expiration, the volume of the balloon at FRC should not be too large. This can be adjusted by opening the vent before the demonstration of inspiration and expiration.)

Another concept that was easily explained using this model was the fact that the intrapleural pressure was negative. This was further enforced when the vent was opened, simulating a penetrating injury to the chest wall, resulting in a pneumothorax. Air rushed into the bottle, causing the balloon to collapse (Fig. 2D).

The model was then given to the students to pass around among themselves. During this time, student doubts were clarified. Students tried their hand at pulling and pushing the rubber sheet. It must be mentioned that the model returned intact.

DISCUSSION

The model described can be easily constructed from readily available discarded materials. As both the balloon and rubber sheet were elastic in nature, it resembled the true elastic nature of the lung and chest wall, providing an intuitive understanding of the forces acting at FRC. Inspiration, passive expiration, and forced expiration as well as the effect of a penetrating injury causing a pneumothorax could be shown using this model.

Limitations. The role of surface tension in alveolar elastic recoil could not be shown. The rubber sheet represented both the chest wall and diaphragm together and not individually.

Conclusions. The discussion was appreciated by the students. Although it was possible to demonstrate this model during a didactic lecture, we feel that such presentations can also be made in smaller groups. As the materials are easily available and cost less than US$1 for a single model, students can be asked to construct similar models by themselves.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

P.K. and V.T.O. conception and design of research; P.K. and V.T.O. prepared figures; P.K. and V.T.O. drafted manuscript; P.K. and V.T.O. edited and revised manuscript; P.K. and V.T.O. approved final version of manuscript.

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Fig. 2. A: equilibrium at FRC. The inward recoil of the balloon is balanced by the outward recoil of the rubber sheet. B: balloon volume increases when the rubber sheet is pulled downward, simulating inspiration. C: balloon volume decreases when the rubber sheet is pushed upward, simulating forced expiration beyond FRC. D: air enters the bottle when the vent is opened, simulating a pneumothorax. In B–D, dotted lines represent the position of the balloon and rubber sheet at equilibrium, and solid lines show their final positions.