Objective: Clinical observation has identified cases in which the negative pressures exerted on patient chest drains have appeared to far exceed the level of suction intended. This study was designed to test whether the use of high rates of airflow in typical pleural/mediastinal drainage systems exerts excessively high negative pressures on the chest drainage tube.

Methods: Three pleural drainage systems were tested in vitro at negative pressure settings ranging, in 5-cm H2O increments, from 5 to 35 cm H2O. At each negative-pressure setting, each device was tested with three different rates of airflow. The negative pressures exerted in the chest drain were measured by water manometer and were compared with the initial pressure settings.

Results: When a high rate of airflow was used, all three systems produced negative pressures that exceeded the pressure level initially set; two of the systems exerted negative pressures that were approximately double those intended, for all pressure settings.

Conclusions: Pleural drainage systems may exert excessive and potentially dangerous high negative pressures if high airflow is utilized. The risk to patients will be minimized if the airflow through the pressure-regulating chamber of the drainage system is adjusted to produce slow, consistent bubbling. High rates of bubbling and turbulence in the water column indicate that the negative pressure level may be excessively high, particularly for patients who do not have air leakage.

Key words: drainage; empyema; pleural; suction

For patients with empyema, a simple water seal bottle can assist pleural drainage, but the application of negative pressure (pressure range, −10 to −40 cm H2O) to the chest drain is far more effective at draining the pleural space. Various pleural drainage devices are routinely used with institutional wall suction systems to treat these patients; under normal circumstances, these devices provide reliable and safe drainage. However, we have observed clinical cases in which the negative pressure in the chest tube seemed to far exceed the pressure setting in the drainage unit, especially when the rate of airflow was high.

Excessive negative pressure levels may cause perpetuation of air leaks, increased air steal, and even hypoxia. A segment of the lung or the content of the mediastinum (a vein graft, for example) may become trapped in the holes of the chest catheter, impairing proper drainage or blocking the whole lumen of the chest or mediastinal catheter. High negative pressure may even damage the tissue or tear it away when the catheter is removed (Yaron Bar-El; personal communication; July 25, 1995).

Typical thoracic drainage devices are designed to produce a desired negative pressure by adjusting the height of a water column in the pressure-regulating chamber according to calibration markings on the device. Theoretically, the drainage device will then regulate the negative pressure, regardless of the rate of airflow or the level of negative pressure exerted by the wall suction system. To investigate the safety and reliability of this calibration method in controlling negative pressure levels, this in vitro study compares, under different conditions of airflow, the negative pressures actually exerted by several typical drainage devices with their initial pressure settings.

Materials and Methods

Pleural Drainage Systems

The three-bottle system for pleural drainage is the basis for most thoracic drainage systems in use today. In this arrangement,
one compartment acts as a fluid collection bottle, the second as a water seal that prevents aspiration of air back into the pleural space, and the third as a pressure-regulating chamber, all incorporated into one disposable plastic unit (Fig 1).

The level of the negative pressure applied to the chest tube is determined in the pressure-regulating chamber. This is a sealed, graduated compartment that has the following three external conduits: (1) a flexible tube connected to an outlet of a wall vacuum system, usually fitted with a simple on/off knob; (2) an atmospheric vent, consisting of a plastic or metal tube that extends down from an opening at the top of the chamber; and (3) a connection from the top of the chamber through the water seal compartment and collecting bottle to the patient’s chest drain.

Adjusting either the height of the water column or the depth of the atmospheric vent tip in the pressure-regulating chamber sets the negative pressure exerted in the chest tube. When the wall vacuum system is turned on, the pressure in this compartment is reduced, and air is sucked from the outside through the atmospheric vent to the bottom of the chamber where it bubbles up through the water column and into the wall suction unit. Because of the pressure exerted by the water column, the net negative pressure created above the water, and thus in the chest drain, is relative to the difference in height between the top of the water column and the lower tip of the atmospheric vent tube.

The following three commercially available and commonly used chest drain systems were studied: (1) the Silberman Glass Pleural Drainage System (Silberman Ltd; Petach Tikva, Israel); (2) the Thorametric 1600 (Biometrix Ltd; Jerusalem, Israel); and (3) the Heyer Drainage System (Carl Heyer GmbH; Bad Ems, Germany). In systems 1 and 2, the negative pressure settings are adjusted by adding water to the pressure-regulating chamber, while system 3 is adjusted by changing the height of the venting tube in a preset and constant amount of water.

Negative Pressure Measurements

The systems were prepared according to the manufacturer’s instructions and then were tested for leaks. The distal end of each system, normally connected to the patient’s chest drain, was connected instead to a water manometer, consisting of a U-shaped transparent plastic tube filled with water that was attached to a vertical graduated ruler (Fig 2). When the valve in the wall vacuum was opened, the height of the water column in the manometer measured the level of negative pressure exerted in the chest drainage tube.

Each drainage system was sequentially adjusted for negative pressures ranging from $-5$ to $-35$ cm H$_2$O, in increments of 5 cm H$_2$O. For each pressure setting, the negative pressure actually exerted was measured at three different rates of airflow. Because current devices and wall suction units lack precise regulators for the rate of airflow, we defined these three categories of airflow according to indicators that are readily identified in the clinical setting. The formation of single, well-defined bubbles that rose in succession to the top of the water column in the pressure-regulating chamber corresponded with low airflow. The simultaneous formation of several well-defined bubbles that rose to the top of the chamber without disrupting the shape of the water column indicated intermediate airflow. The formation of numerous bubbles and turbulent jets of air that caused complete disruption of the water column indicated high airflow. The three levels of airflow were achieved by manually adjusting the knob of the wall vacuum system. To account for possible variations between devices due to manufacturing variability, three different devices of each kind of system were tested.

Results

Many of the negative pressures recorded by manometer were substantially higher than the pressure levels originally set in the pressure-regulating chamber. Table 1 summarizes the negative pressure levels measured for each system at different pressure settings under different conditions of airflow. The differences between individual devices of the same

![Figure 1. The three-bottle drainage system.](http://journal.publications.chestnet.org/pdfsaccess.ashx?url=/data/journals/.../21958/ on 04/18/2017)
system were negligible. When systems 1 and 2 were tested with high water levels and high airflow, some of the water was drawn up the tubing into the wall vacuum system. In this situation, the actual negative pressure applied to the pleural space became dangerously high and could not be accurately measured by the manometer.

**DISCUSSION**

It is commonly assumed that once a pleural drainage device is set to a desired negative pressure level, the pressure exerted by the water column in the pressure-regulating chamber will maintain the desired negative pressure, regardless of the wall suction or airflow applied to the drainage system. Typical pleural drainage systems can be filled to a maximum level of 30 or 40 cm H$_2$O in the pressure-regulating compartment, thus theoretically limiting the negative pressure generated to between −30 and −40 cm H$_2$O. Although a few commercial systems also incorporate a high negative pressure valve at −40 cm H$_2$O to prevent excessive negative pressures, most systems commonly used, and those tested herein, do not incorporate this feature.

This relationship between the calibration of the water level in the device and the actual pressures produced holds true only if there are no air leaks in the system, the only connection to the atmosphere is through the tube immersed at the bottom of the water column, the inflow of air through the venting tube is unobstructed, and the tube is large enough to accommodate the high rates of airflow generated by the wall suction unit.

In patients with air leaks from the lung, significant negative pressures and higher airflow rates are required to maintain adequate drainage. Previous studies have shown that in most clinical settings, air leakage from the lungs ranges from <1 to 16 L/min. Measurements of the wall vacuum unit in our hospital recorded an airflow between 50 and 70 L/min at negative pressures between 500 and 550 mm Hg (650 to 715 cm H$_2$O). Other studies have reported airflow rates of 40 L/min. These rates of airflow are far greater than necessary, even for patients with considerable air leakage from the lung.

When the valve on the wall suction unit is fully opened, as typically happens, between 40 and 70 L/min should flow through the atmospheric vent tube. Any obstruction of the airflow in the atmospheric vent tube will cause the pressure in the

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<tr>
<th>Table 1—Comparison of Negative Pressure Settings in Pleural Drainage Systems With Negative Pressures Exerted$^*$</th>
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<tbody>
<tr>
<td>Degree of Bubbling</td>
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$^*$Values given as negative pressure exerted.

†Pressure could not be measured by manometer because of suction of water into the wall vacuum system.

‖This system did not have a calibration marking for this pressure.
chamber to increase, potentially reaching the full suction capability of the wall vacuum system when there is a complete obstruction of the vent. The rate of airflow through the atmospheric vent tube is governed by Poiseuille’s equation, with a linear relationship to the tube’s length and an exponential relation to the fourth power of the radius of the tube. The internal diameters of the venting tubes in this study were 5 mm in system 1 and 6 mm in systems 2 and 3. A tube with an internal diameter of 6 mm allows a maximum flow of 15.1 L/min at −10 cm H₂O of suction. The small diameter of the air vent tubes thus posed a resistance to these higher rates of air flow commonly found in wall suction systems and may have caused the negative pressure inside the pressure-regulating chamber to increase.

**Conclusion**

Many medical personnel are unaware that conventional drainage systems can generate excessive negative pressure under certain conditions. This study highlights the potential for dangerously high negative pressures ensuing from drainage devices used with high rates of airflow. Because the three systems tested herein are fairly typical of commercial devices utilizing water to regulate negative pressure levels, similar devices may generate similarly excessive negative pressures when used with a high rate of airflow. Whenever pleural suction is clinically indicated, the airflow requirements of the patient and the rate of airflow through the drainage system should be considered as carefully as are pressure requirements. Most patients, with little or no air leakage, require only a low rate of airflow, which can be assured by adjusting the airflow at the wall connection to produce single, well-formed bubbles that rise in consistent succession in the pressure-regulating chamber. This is indicative of a safe level of negative pressure and sufficient airflow. Turbulent bubbling should be considered as a clear warning that the negative pressure in the patient’s chest drain may be dangerously high. Optimally, all wall suction systems would be equipped with a mechanism to precisely regulate the rate of airflow or all pleural drainage systems would incorporate a valve to prevent the development of such dangerously high negative pressures, even in the presence of high rates of airflow.

**References**

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