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(54) **VENTILATOR TEST LUNG AND TRIGGER ASSEMBLY**

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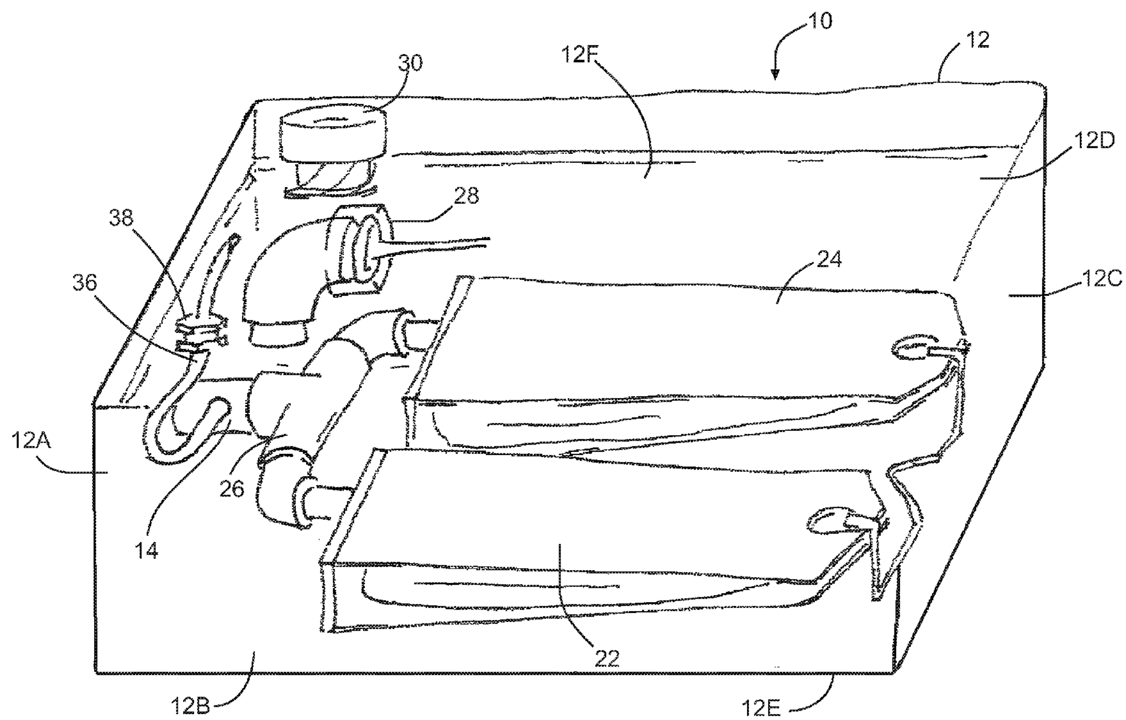
(57) **ABSTRACT**

A simulated mechanical respiratory trigger and test lung have been developed. The trigger in one embodiment is capable of triggering a variety of mechanical ventilators to deliver predetermined respiratory rates that simulate a spontaneously breathing patient. This permits the student/health care provider to respond to this spontaneous effort and optimize mechanical ventilator settings. The test lung in an embodiment is capable of varying the simulated patient pulmonary compliance in increments not previously available.



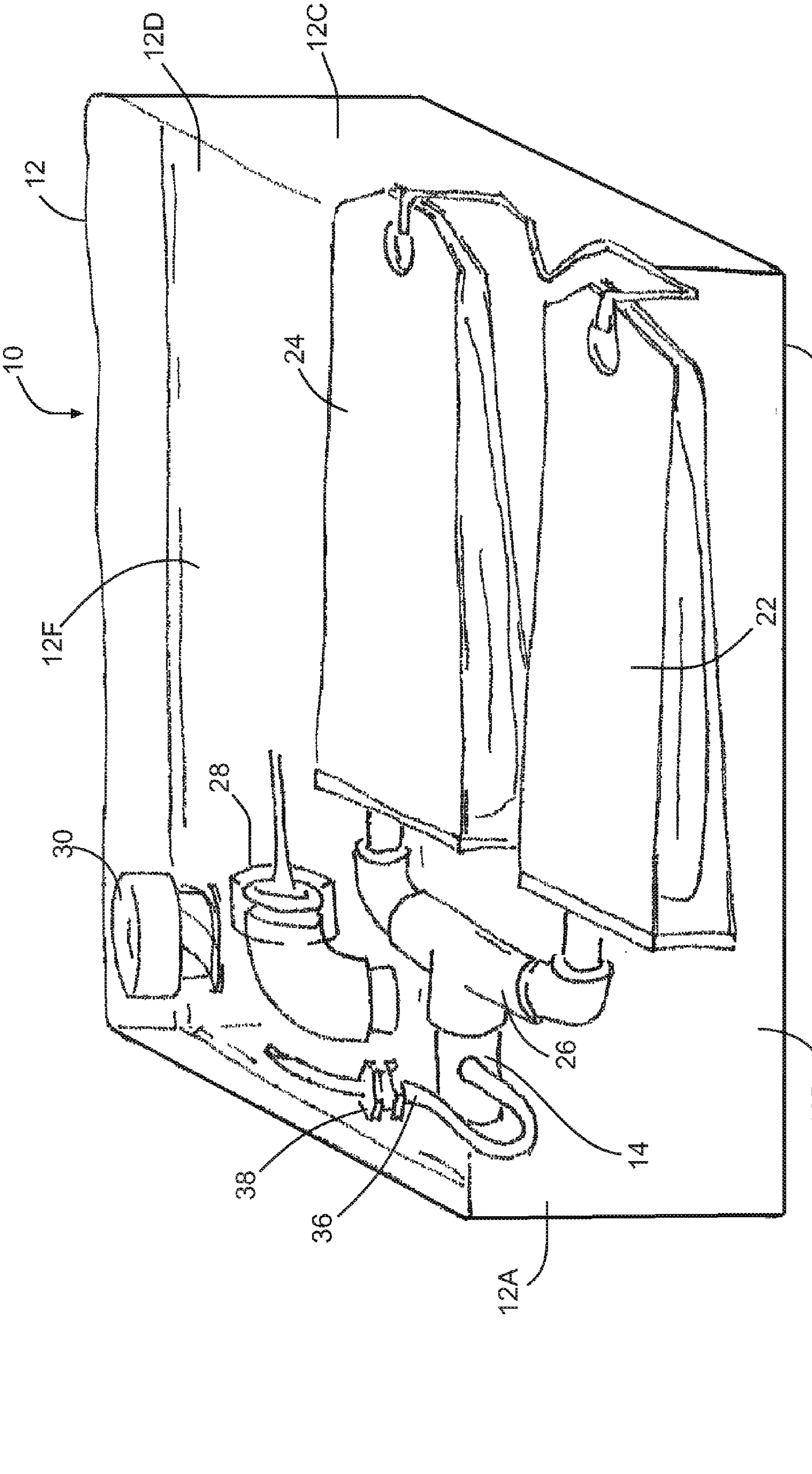
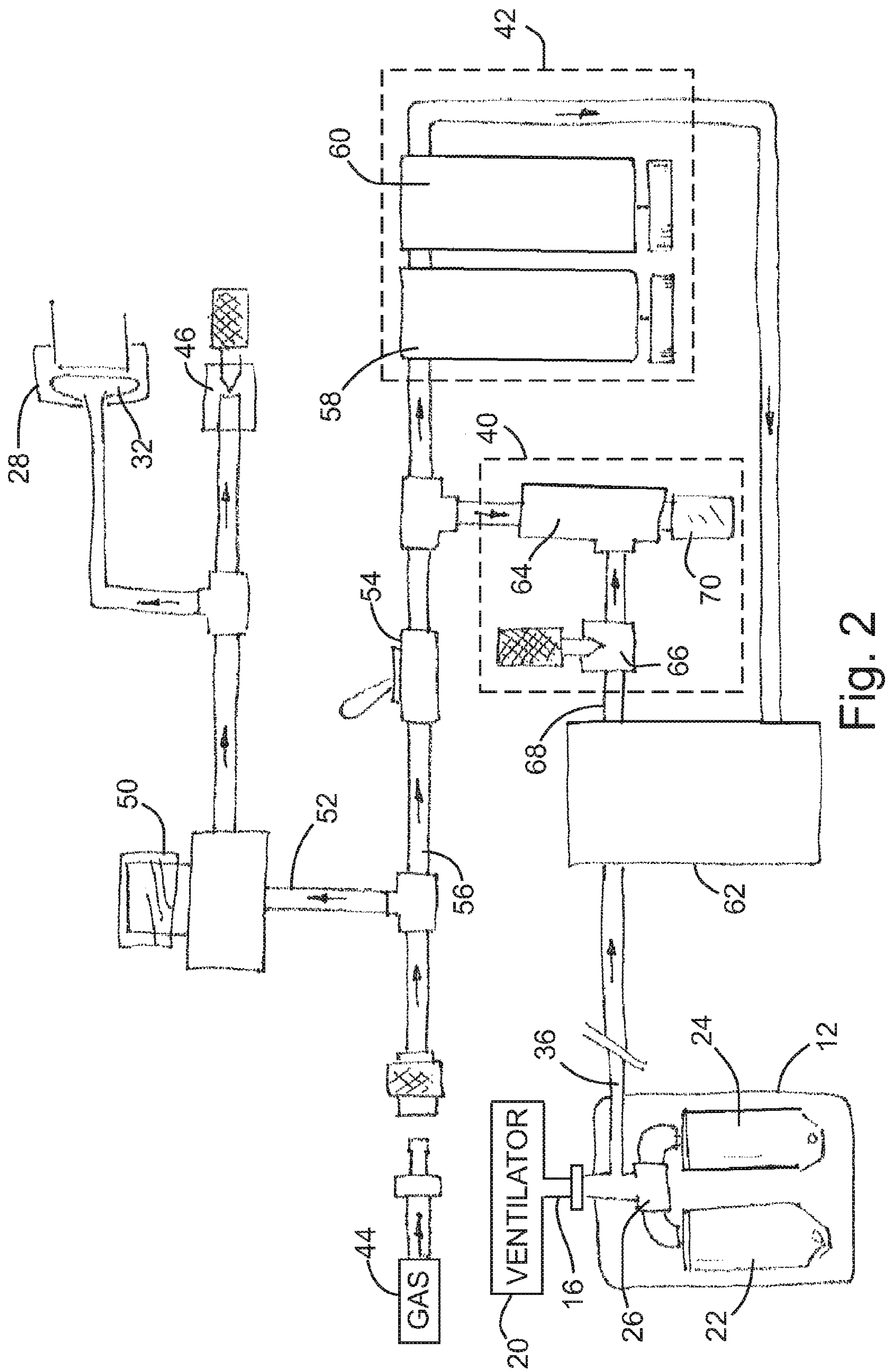


Fig. 1


42
60
58
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64
70
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56
62
Fig. 2
36
24
12
GAS
44
VENTILATOR
16
26
22
20

Fig. 2

VENTILATOR TEST LUNG AND TRIGGER ASSEMBLY

TECHNICAL FIELD

[0001] Test lungs for use with ventilators

BACKGROUND

[0002] Test lungs are used in the education of respiratory therapy students in a laboratory setting. These labs include the use of a variety of mechanical ventilators currently in use in critically ill, post-operative, and chronically ill patients. Test lungs are available but current systems either do not offer adjustable pulmonary compliance (stiffer or floppier patient lungs) or utilize mechanical devices such as springs that are cumbersome to adjust in real time simulation or offer a limited number of predetermined settings. These systems also tend not to incorporate a trigger device. A trigger device permits the inanimate test lung to initiate a breath by generating an inspiratory flow through the use of applied suction to the breathing system that includes both the lung simulator and the mechanical ventilator of choice. This inspiratory flow is sensed by the mechanical ventilator as a patient effort through the use of flow sensing components and will then respond as it would in human patient use by delivering a mechanical breath.

SUMMARY

[0003] A simulated mechanical respiratory trigger and test lung have been developed. The trigger in one embodiment is capable of triggering a variety of mechanical ventilators, as a spontaneously breathing patent would, to deliver predetermined respiratory support. This permits the student/health care provider to respond to this spontaneous effort and optimize mechanical ventilator settings. The test lung in an embodiment is capable of varying the simulated patient pulmonary dynamic compliance in increments not previously available to the knowledge of the inventor.

[0004] Thus in an embodiment, there is provided a test lung for a ventilator, the test lung comprising a rigid container having fixed walls, the rigid container being pressure tight to a working pressure above atmospheric pressure; an inflow line in a wall of the rigid container for connecting to a hose from a ventilator; at least a first expandable chamber disposed within the rigid container, the first expandable chamber being connected to receive gas passing through the inflow line; and a valve arrangement disposed in one or more walls of the rigid container, the valve arrangement providing controlled gas flow into and out of the rigid container.

[0005] In another embodiment, there is provided a pneumatic trigger for a ventilator, the pneumatic trigger comprising: at least a trigger hose connectable to a ventilator output; a gas operated timing mechanism connected via a controller on the trigger hose to allow or block flow through the trigger hose according to settings of the timing mechanism; and a vacuum generator on the trigger hose to provide suction on the trigger hose when the controller is set to allow flow through the trigger hose.

[0006] These and other aspects of the device and method are set out in the claims, which are incorporated here by reference.

BRIEF DESCRIPTION OF THE FIGURES

[0007] Embodiments will now be described with reference to the figures, in which like reference characters denote like elements, by way of example, and in which:

[0008] FIG. **1** is a diagram illustrating an embodiment of a test lung; and

[0009] FIG. **2** is a schematic showing an embodiment of a pneumatic control circuit providing a pneumatic trigger and variable compliance for the test lung.

DETAILED DESCRIPTION

[0010] Immaterial modifications may be made to the embodiments described here without departing from what is covered by the claims.

[0011] A test lung **10** is provided for a ventilator (not shown in FIG. **1**, but see element **20** in FIG. **2**). The test lung comprises a rigid container **12** having fixed side walls **12**A, **12**B, **12**C and **12**D, fixed bottom wall **12**E and fixed top wall **12**F. The rigid container may be formed at least partially from a Pelican™ brief case or other shock proof container. In some embodiments, for example when the rigid container **12** is a Pelican™ brief case or other case having a lid, the top wall **12**F may be formed by a plate sealed to the walls **12**A-D by a suitable gasket (not shown) extending around the inside of the walls **12**A-D. The plate forming the wall **12**F may be a transparent plate made of acrylic or other suitably strong material to allow students to observe the mechanism of the test lung. The rigid container **12** should be pressure tight to a working pressure above atmospheric pressure. The working pressure should be at least as high as required for operation with a conventional ventilator.

[0012] An inflow line **14** is provided in a wall, such as wall **12**A of the rigid container **12**, for connecting to a hose **16** from ventilator **20**. A first expandable chamber **22** and a second expandable chamber **24** are disposed within the rigid container **12** and are connected via flow T **26** to receive gas passing through the inflow line **14**. The chambers **22**, **24** may have any suitable design for a test lung and may be bladders. A valve arrangement **28**, **30** is disposed in one or more walls such as wall **12**F of the rigid container **12** for convenience. The valve arrangement **28**, **30** provides a controlled gas flow into and out of the rigid container **12**. The valve arrangement **28**, **30** includes at least a first valve **28** having a valve element **32** oriented to provide variable resistance to gas flow out of the rigid container **12**. The first valve **28** may be a mushroom valve. The valve arrangement **28**, **30** includes a check valve **30** oriented to prevent gas flow out of the rigid container **12** and allow gas flow into the rigid container **12**. A trigger hose **36** is connected to the inflow line **14** and passes through the wall **12**F through a suitable seal **38**.

[0013] Referring to FIG. **2**, the pneumatic control circuit shown, which may conveniently be housed in the same case as the test lung, for example within a Pelican™ case, provides variable resistance for the first valve **28**, a suction mechanism **40** for the trigger hose **36** and a gas operated timing mechanism **42** for controlling flow on the trigger hose **36**. Conveniently, all gas powered parts of the pneumatic control circuit may be powered by a gas source **44** such as a conventional wall air source in a medical facility or educational laboratory, which may have a pressure range from 35-75 psig for example. Variable resistance of the first valve **28** is controlled by a control valve **46** that is operable to change an amount of gas directed to the first valve **28** from the gas source **44** by manual operation of the valve **46**, which may be a needle valve. Higher pressure on the first valve **28** established by closing the valve **46** provides a greater resistance to expansion of the expandable chambers **22** and **24**. Use of valve **46** allows setting of the compliance of the test lung at a continuous range of values. Gas regulator **50** on the line **52** from the gas source **44** to the first valve **28** may be used to regulate downward the pressure supplied to the first valve **28** depending on the operational requirements of the first valve **28**.

[0014] Gas operated timing mechanism **42** is connected to the gas source **44** via a switch **54** on line **56** that allows the timing mechanism to be turned on and off. Gas operated timing mechanism **42** includes in an embodiment a first timing module **58** that controls length of an inspiratory effort from the vacuum generator **64** and a second timing module **60** that controls frequency of an inspiratory effort from the vacuum generator **64**. The gas operated timing mechanism **42** is connected via a controller **62** on the trigger hose **36** to allow or block flow through the trigger hose **36** according to settings of the timing mechanism **42**.

[0015] Flow through the trigger hose **36** may be actuated by a vacuum generator **64**, such as a venturi, connected to receive gas power from gas source **44** through line **56** and expel gas out through a muffler **70**. A valve **66** on line **68** may be used to regulate the amount of suction provided on line **68** by vacuum generator **64**. The controller **62** is a conventional controller that opens or closes line **68** depending on pneumatic signals from the timing mechanism **42**.

[0016] The test lung and pneumatic trigger assembly operates in an embodiment as follows. The compliance, or the amount of effort required to expand the expandable chambers **22**, **24**, is set by the degree of opening of valve **28**, which in turn is controlled by the amount of air diverted through valve **46**. The degree of compliance may be changed as desired. The trigger may be activated by throwing switch **54**. The duration and frequency of a trigger signal from the gas operated timing mechanism is set by manual setting of the modules **58** and **60**. When the gas operated timing mechanism **42** sends a signal to the controller **62** to signal the initiation of an inspiratory effort, the controller **62** opens line **68** and the vacuum generator **64** causes a low pressure to develop on line **68**, which causes a low pressure on trigger hose **36** and thus inflow line **14**. The low pressure or suction on inflow line **14** signals to the ventilator **20** to commence an inspiratory effort. As the timing mechanism sends periodic on signals to the controller **62**, the operation of the ventilator **20** may be triggered as required.

[0017] The simulated respiratory trigger and test lung is therefore capable of triggering a variety of mechanical ventilators (those that respond to an inspiratory effort in adult, pediatric and neonatal patent populations) to deliver predetermined respiratory rates that simulate a spontaneously breathing patient. This permits the student/health care provider to respond to this spontaneous effort and optimize mechanical ventilator settings.

[0018] The simulated respiratory trigger and test lung is also thus capable of varying the simulated patients pulmonary compliance in increments not previously available to the knowledge of the inventor. If delivering a preset tidal volume, patient peak airway pressures may be altered in 1 cm/H2O increments from normal adult ranges to exceedingly high values (>50 cmH2O). This is accomplished through manipulating control valve **46**, which may be a single control on the exterior of the rigid container **12**. Respiratory rate is also manipulated with a single control for the module **60**, the control switch of which may also be conveniently located on the exterior of the rigid container **12**.

[0019] The simulated respiratory trigger and test lung does not in one embodiment require a/c power but may be run on compressed air at 50 PSI, which is the routine operating pressure of mechanical ventilators and should therefore be readily available for use anywhere mechanical ventilators are in use. With the use of an air cylinder of compressed gas, the test lung and trigger could also be used in patient transport simulations.

[0020] The simulated respiratory trigger and test lung may also display and produce waveforms and physiological flow patterns that demonstrate expiratory flow limitations that are present in asthmatic or COPD patients to the student. COPD, or chronic obstructive pulmonary disease, is increasing in prevalence in our current generation. It is also possible to run the test lung alone that can still vary simulated patient compliance without the need of compressed air. The trigger would be non-functional in this configuration.

[0021] Coupling a ventilator trigger device with a new method for altering pulmonary compliance permits a degree of simulation for the student and instructor to: 1) allow students to see and respond appropriately to changing patient compliance in the adult, pediatric and neonatal patient populations, 2) allow students to see and respond to a range of patient respiratory rates from apnea (no breath rate) to tachypnea (respiratory rates as high as 40 breathes per minute), 3) have several devices set up with different parameters in a lab setting to simulate an entire hospital unit of patients, 4) provide equitable and repeatable lab testing scenarios, 5) bench testing of newly acquired ventilators in the hospital setting to ensure appropriate operation prior to using the device on patients, and 6) use the device in education of a variety of health care providers including but not limited to respiratory therapists, paramedics, physicians, physician assistants, anesthesiologists, and anesthesiologist assistants, and specific nursing programs.

[0022] In the claims, the word "comprising" is used in its inclusive sense and does not exclude other elements being present. The indefinite article "a" before a claim feature does not exclude more than one of the feature being present. Each one of the individual features described here may be used in one or more embodiments and is not, by virtue only of being described here, to be construed as essential to all embodiments as defined by the claims.

1. A test lung for a ventilator, the test lung comprising:

a rigid container having fixed walls, the rigid container being pressure tight to a working pressure above atmospheric pressure;

an inflow line in a wall of the rigid container for connecting to a hose from a ventilator;

at least a first expandable chamber disposed within the rigid container, the first expandable chamber being connected to receive gas passing through the inflow line; and

a valve arrangement disposed in one or more walls of the rigid container, the valve arrangement providing controlled gas flow into and out of the rigid container.

2. The test lung of claim **1** in which the valve arrangement includes at least a first valve having a valve element oriented to provide variable resistance to gas flow out of the rigid container.

3. The test lung of claim **2** in which variable resistance of the first valve is controlled by a control valve that is operable to change an amount of gas directed to the first valve from a gas source.

4. The test lung of claim **3** in which the first valve comprises a mushroom valve.

5. The test lung of claim **1** in which the valve arrangement includes a check valve oriented to prevent gas flow out of the rigid container and allow gas flow into the rigid container.

6. The test lung of claim **1** further comprising a pneumatic trigger for the ventilator, the pneumatic trigger comprising at least a trigger hose connected to the inflow line.

7. The test lung of claim **6** in which the pneumatic trigger comprises a gas operated timing mechanism.

8. The test lung of claim **7** in which the gas operated timing mechanism is connected via a controller on the trigger hose to allow or block flow through the trigger hose according to settings of the timing mechanism.

9. The test lung of claim **8** in which the flow through the trigger hose is actuated by a vacuum generator.

10. The test lung of claim **6** in which the rigid container houses the pneumatic trigger.

11. The test lung of claim **1** in which the rigid container comprises a shock proof brief case.

12. The test lung of claim **1** in which:

the valve arrangement includes at least a first valve having a valve element oriented to provide variable resistance to gas flow out of the rigid container, variable resistance of the first valve being controlled by a control valve that is operable to change an amount of gas directed to the first valve from a gas source;

a trigger hose connected to provide a flow line between the inflow line and a pneumatic trigger, the pneumatic trigger including a gas operated timing mechanism connected via a controller on the trigger hose to allow or block flow through the trigger hose according to settings of the timing mechanism, flow through the trigger hose being actuated by a vacuum generator; and

the gas source being connected to provide gas for the gas operated timing mechanism and to power the vacuum generator.

13. The test lung of claim **12** in which the gas source comprises a wall air source in a medical facility or educational laboratory.

14. The test lung of claim **12** in which the valve arrangement includes a check valve oriented to prevent gas flow out of the rigid container and allow gas flow into the rigid container.

15. A pneumatic trigger for a ventilator, the pneumatic trigger comprising:

at least a trigger hose connectable to a ventilator output;

a gas operated timing mechanism connected via a controller on the trigger hose to allow or block flow through the trigger hose according to settings of the timing mechanism; and

a vacuum generator on the trigger hose to provide suction on the trigger hose when the controller is set to allow flow through the trigger hose.

16. The pneumatic trigger of claim **15** in which the gas operated timing mechanism is powered by a gas source and the vacuum generator is powered by the gas source.

17. The test lung of claim **16** in which the gas source comprises a wall air source in a medical facility or educational laboratory.

18. The pneumatic trigger of claim **15** in which the gas operated timing mechanism comprises at least a first timer to control frequency of flow through the trigger hose and a second timer to control duration of flow through the trigger hose.

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