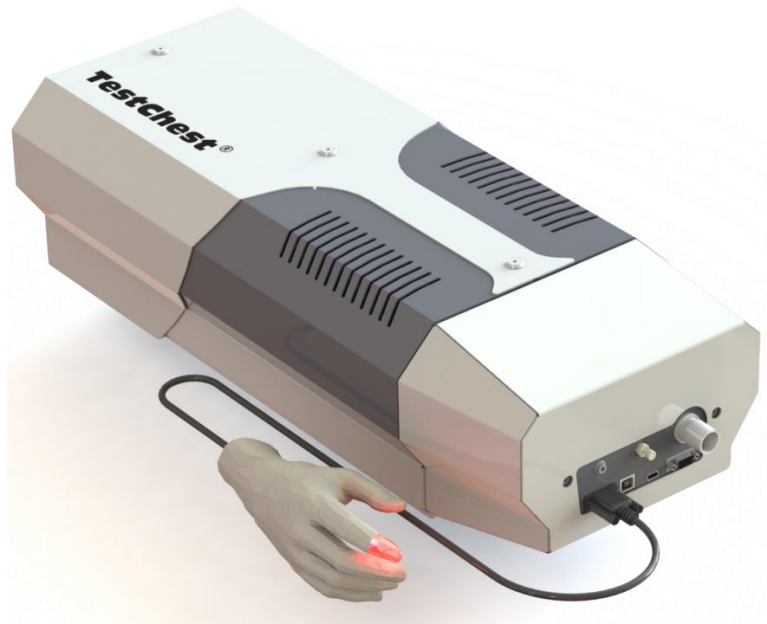


TestChest®



TestChest® Basic Software

Basics of Artificial Ventilation



AQAI
SIMULATIONSZENTRUM MAINZ



ORGANIS

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Basic Software Installation

Together with TestChest® you will receive an executable file for the installation of the TestChest® Basic Software.

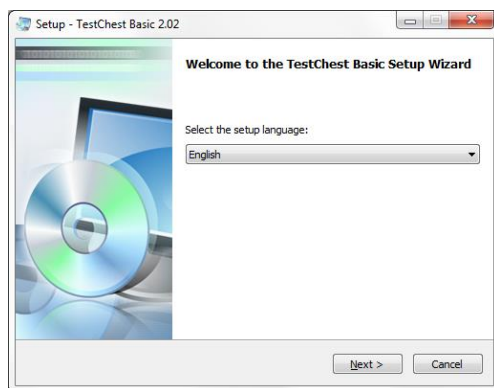
It is labeled like

“TestChest_Basic_x_yz.exe”

“x” denominates the main version number, “y” and “z” version sub numbers. If in doubt, ask Organix or AQA! about the latest version of the Basic Software.

Execute this file. You will be prompted by Windows to grant rights to the software. Click on “YES”.

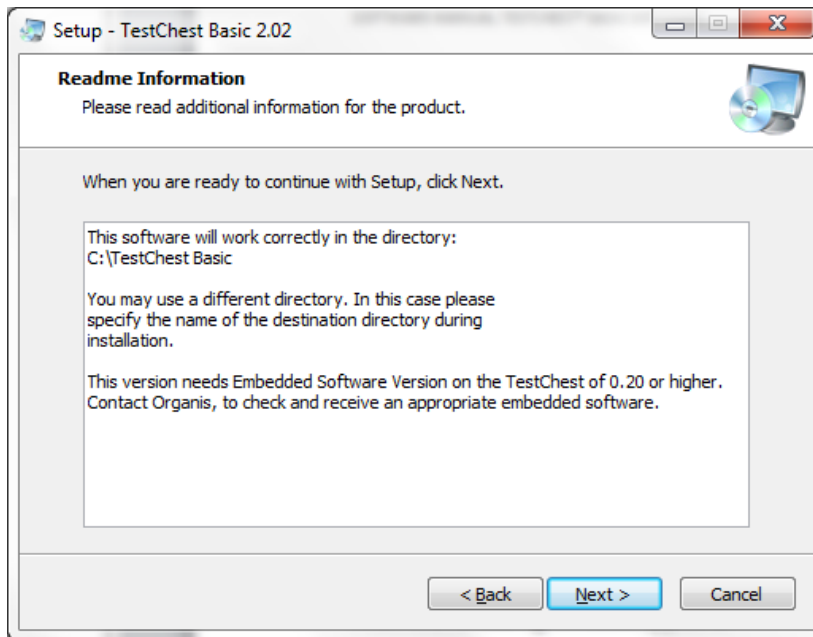
The following window appears:



Select your desired installation language and follow the directions.

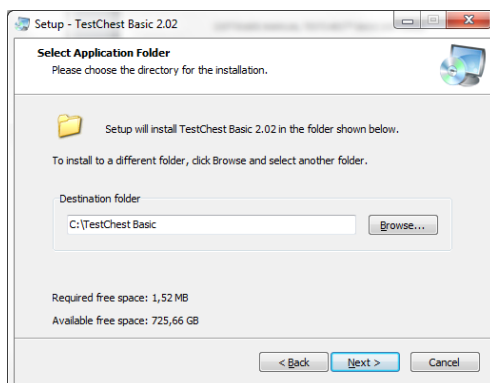
Please take a look at the Readme file; it may give some important information.

BASIC SOFTWARE INSTALLATION

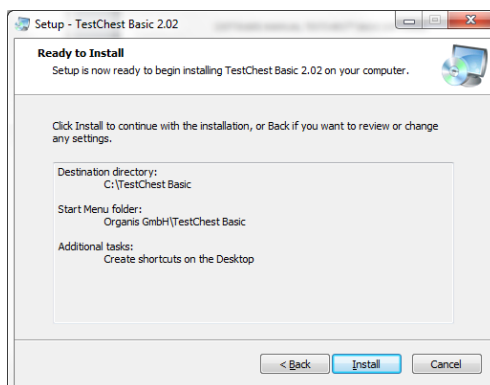


The embedded software loaded onto TestChest has to be compatible with the version of the basic software. If in doubt, please contact Organix or AQAI for more information. All TestChest delivered later than September 2014 will have at least the embedded version 0.20

You can accept or change the installation folder:

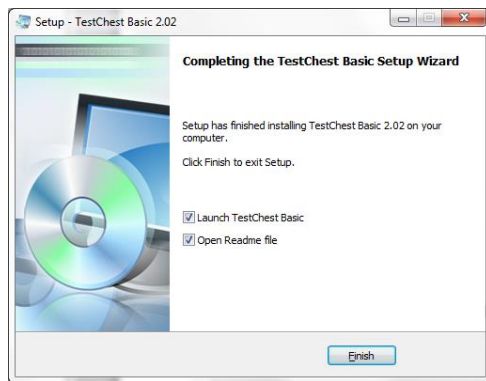


Finally the Start Menu and the desktop icons will be created.



BASIC SOFTWARE INSTALLATION

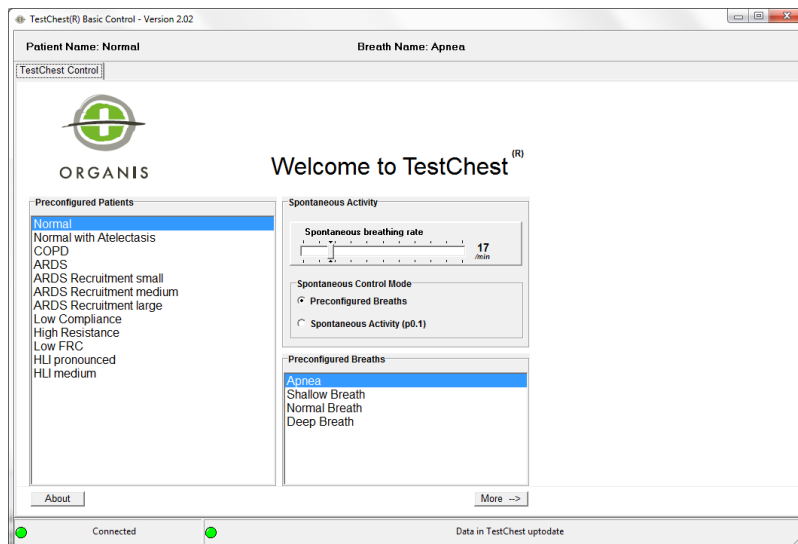
This dialog indicates that everything has worked well:



Before you start the application, make sure that TestChest is connected by an Ethernet cable (see next chapter) and switched on.

If everything works fine, you will be greeted by the TestChest Basic Software welcome page.

TestChest® Basic Software Welcome Page

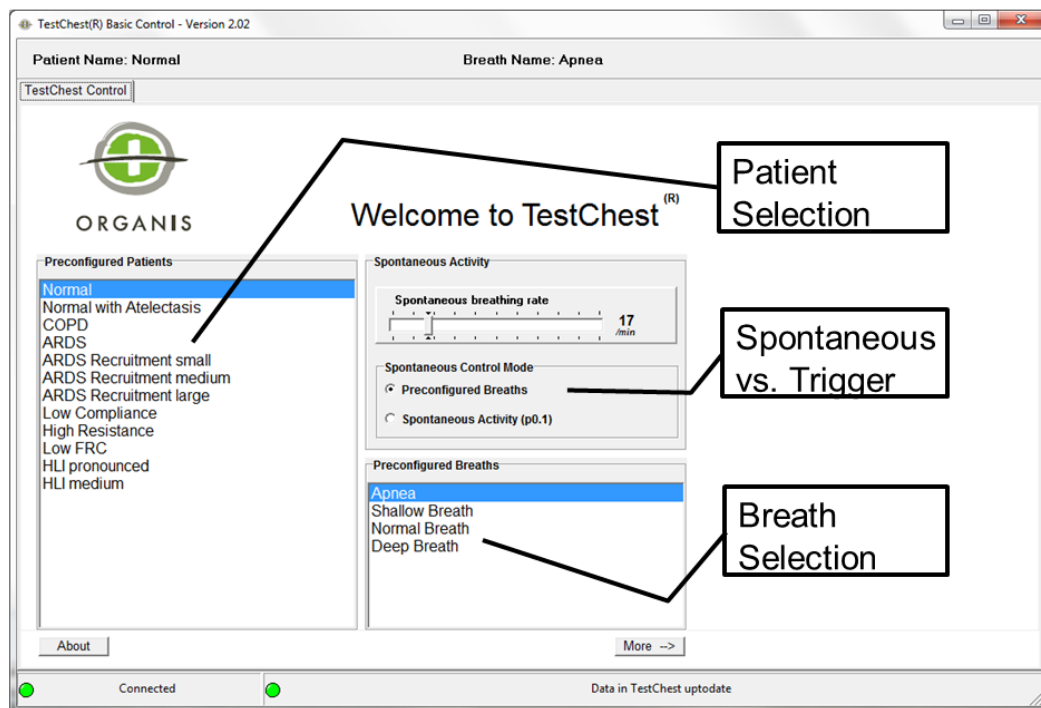


Please look at the 2 indicators in the bottom part of the page: they should look green. If not: go to the last chapter or read the TestChest manual. Remark: if measurement stream is on (see chapter "Measurement") the left indicator shows blue color. This indicates normal operation during measurement.

Basic Software Screen Shots

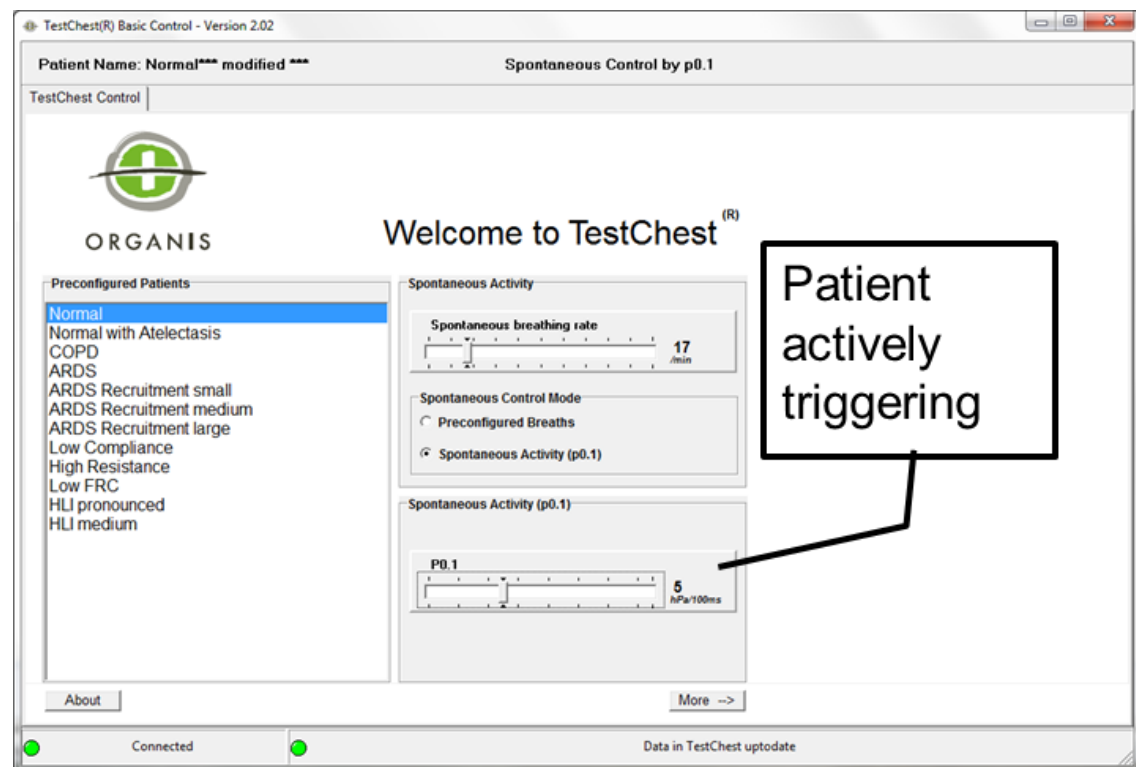
The following pages show some screen shots and some explanations how to use the basic software.

TestChest® welcome page



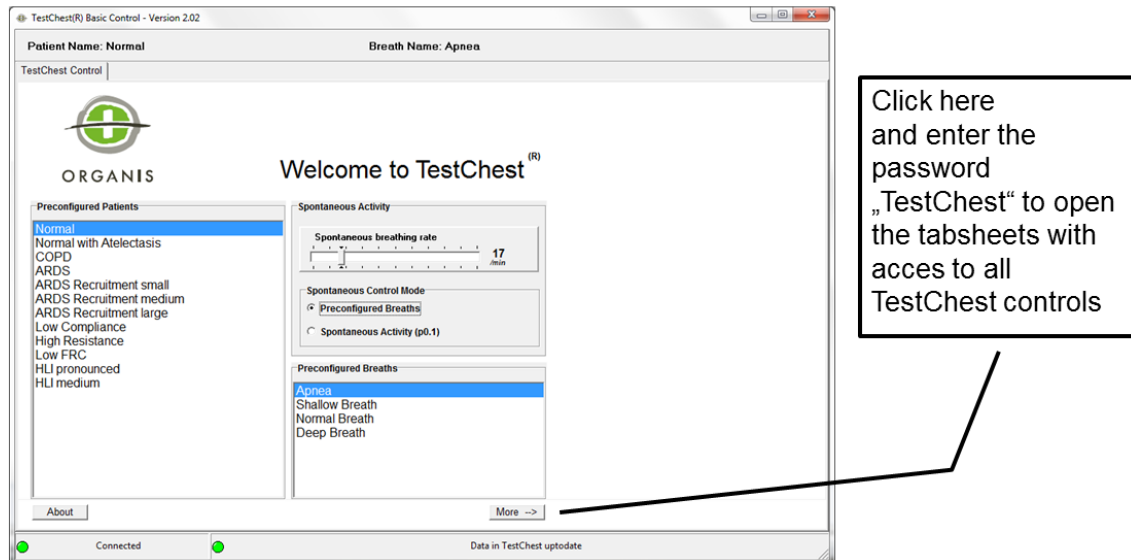
The TestChest welcome page offers the possibility of selecting a certain patient. By default the software starts with the “Normal” patient. On the bottom of the right part some spontaneous breaths can be selected. Furthermore, this page allows selecting the spontaneous breathing rate (if a spontaneous breath or a spontaneous activity (P0.1) is present (see next page).

Remark: If the preconfigured breath “Apnea” is selected, spontaneous breathing will not occur except P0.1 activity is used, i.e. the slider “Spontaneous breathing rate” will be effective only in P0.1 mode.



This picture shows the possibility of selecting a certain P0.1 as active inspiration impulse. P0.1 is the pressure, which would be generated after 0.1 sec (100 ms), if the airway would be blocked during inspiration. Thus it represents the activity from the diaphragm.

How to access the extended mode



To access the detailed pages, where all parameters of the TestChest can be set, it is necessary to login. The default password is shown in the picture. Please be aware that the administrator may set a different password.

TabSheet „Lung Mechanics“

TestChest(R) Basic Control - Version 2.02

Patient Name: Normal Breath Name: Apnea

TestChest Control Lung Mechanics Recruitment V / Q Heart Lung Interactions Measurement

Lung Mechanics

Chestwall compliance 150 ml/hPa

Total compliance 60 ml/hPa

Airway resistance ☒ Rp5 ☐ Rp20 ☐ Rp50 ☐ Rp200 Steps

FRC at ZEEP 2000 ml

Lower inflection point LIP 5 hPa

Upper inflection point UIP 35 hPa

Compliance below LIP 25 ml/hPa

Compliance above UIP 20 ml/hPa

☐ Always less than Total Compliance

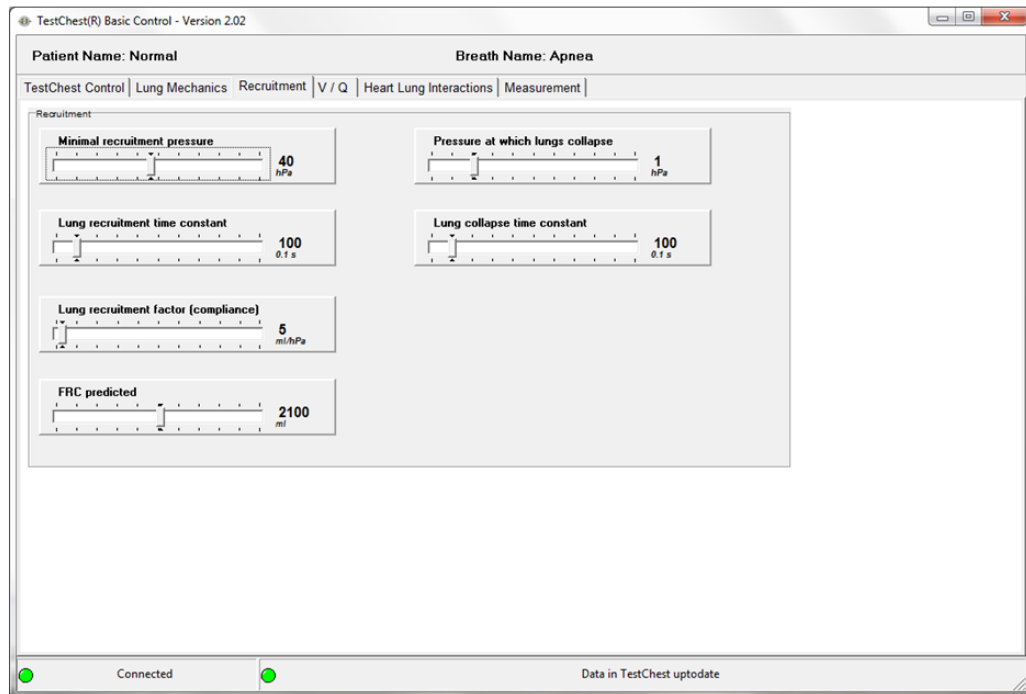
☐ Always less than Total Compliance

Technical

Leakage ☒ none ☐ small ☐ medium ☐ large ☐ none Arbitrary

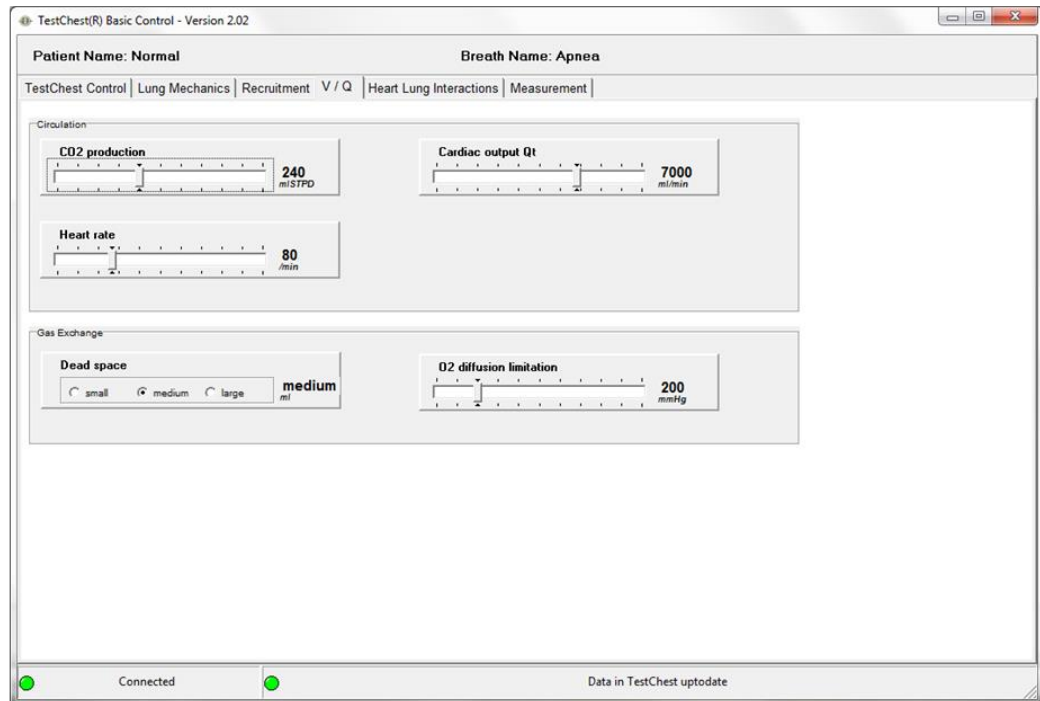
Connected Data in TestChest uptodate

The TabSheet “Lung Mechanics” accesses all parameters that influence the mechanical properties of the TestChest. The most important parameters are compliance and resistance. Moreover it is possible to define the nonlinearity of the inspiratory pressure volume relation here (lower and upper inflection point).



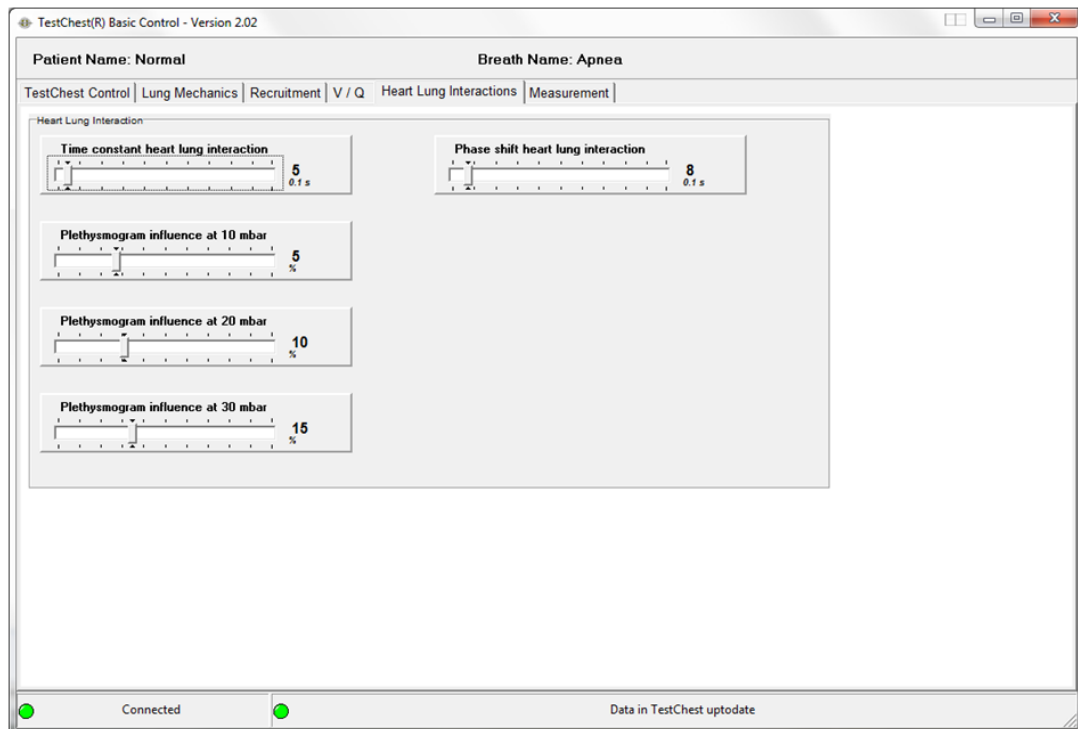
On the Tabsheet “Recruitment” parameters can be influenced which describe the recruitability properties of the TestChest. These parameters are mainly used in the simulation of ARDS patients.

Tabsheet „V/Q“



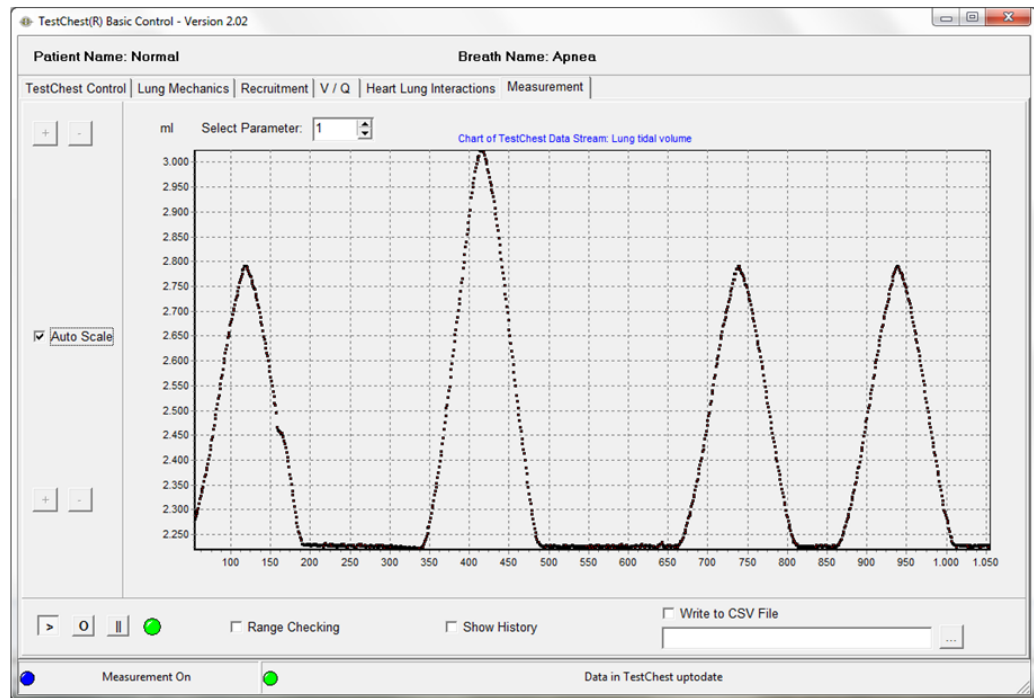
Tabsheet “V/Q” sets the metabolic and circulation parameters of the TestChest. In the lower part 2 parameters for gas exchange are accessible.

TabSheet „Heart Lung Interactions“



Heart Lung Interaction (HLI) occurs, if the pressure generated by the ventilator markedly influences the circulation, especially the flow of blood from the venous system to the right heart. A typical clinical substrate for this is an absolute or relative volume deficit. Clinically HLI is mainly observed by variations in the arterial pressure curve or – if sophisticated hemodynamic methods are available – by Pulse Pressure Variation (PPV).

TabSheet „Measurement“



TestChest can record certain data during any kind of exercise. Please take a look at the chapter “Measurement” to learn more about the various data that can be recorded. If the measurement recording is on, the left indicator will change from green to blue and also the text changes from “Connected” to “Measurement On”.

Basic Learning Contents

This manual collects some of the most basic exercises that can be experienced with the TestChest.

For most of these exercises it is recommended to have the TestChest together with an intubation head, a ventilator capable of all modern modes of ventilation, a pulse oximeter connected to the artificial finger and a main stream CO₂ monitor.

Modern ventilators include all these monitoring options.

With some ventilators it is possible to record various patterns, even static pressure-volume-loops. These machines are very helpful in the learning process.

AQAI has developed several **Learning Modules** that suggest more exercises and also give access to various simulated patients.

These learning modules include:

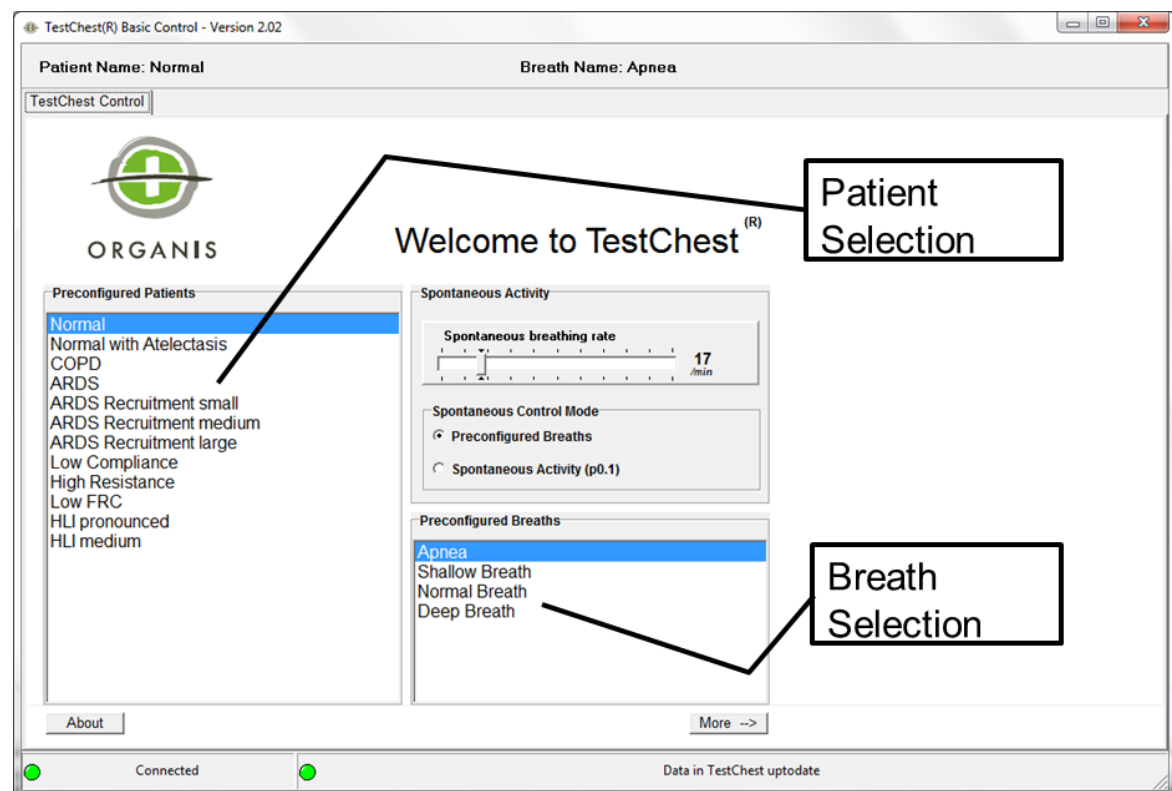
- Basics and Advanced Ventilation
- COPD
- ARDS
- Weaning
- Noninvasive Ventilation
- Transpulmonary Pressure

Patients, Breaths

- You will be able to learn how various patient types show different behavior during controlled and assisted ventilation.
- You will understand to interpret different spontaneous breaths and to see if the patient shows normal, reduced or elevated activity.
- You will learn typical measurement values of a normal patient, a patient with reduced compliance, a patient with elevated resistance, an ARDS patient and a COPD patient.

TestChest has various parameters to define a certain patient or a typical breath.

Preconfigured Patient and Breaths can easily be selected:



Basic Control Software includes management systems for the creation of patients and breaths. (See TestChest Manual, Chapter Basic Control Software)

Preconfigured Patients and Breaths:

- Normal Patient
- Patient with reduced compliance
- Patient with elevated resistance (e.g. asthmatic patient)
- ARDS Patient
- Patient with reduced functional residual capacity (FRC)
- Patient with chronic obstructive lung disease (COPD)

Preconfigured Breaths:

- Apnea (no spontaneous breathing)
- Shallow breath
- Normal breath
- Deep breath

The normal patient has healthy lung conditions. He shows a normal gas exchange at room air, a total compliance of about 60 ml/cmH₂O and a low resistance. He can either be “passive”, e.g. a deeply sedated or anesthetized patient, or “active” by means of doing some trigger work at the beginning of the next respiratory cycle.

The patient with reduced compliance has a total compliance of about 30 ml/cmH₂O. This may be the case in elder patients or during pneumonia. He can be fully passive or active by showing trigger activity.

The patient with elevated resistance can be an asthmatic patient with mild asthma. This leads to longer expiration times and the principal danger of overinflating the lungs. He can be fully passive or active by showing trigger activity.

The ARDS patient shows the typical findings and can be selected either “passive” or “active” with trigger activity.

For more information on ARDS choose the advanced learning module “ARDS”. This learning module contains several cases and a dynamic representation of the disease including various ventilation modes, various severity degrees and weaning strategies.

The patient with reduced functional residual capacity (FRC) can be a patient with scoliosis. This impairs the gas exchange. He can be “passive” or “active”. To check the influence of different FRC levels on the gas exchange, please use the scenario “Low FRC Patient” of the basic learning module.

The patient with chronic obstructive lung disease (COPD) shows the typical findings of such a patient. He has an elevated airway resistance and lung conditions that prolong the final expiration. In these patients this is a representation of the typical air trapping situation in the small airways.

The four preconfigured breaths are “Apnea” which means no spontaneous breathing, “Shallow Breath” with a fairly low tidal volume, “Normal adult breath” and “Deep Breath” like in a sportsman.

Activity:

Connect the ventilator to the TestChest and practice different modes of ventilation (e.g. volume control, pressure control). Observe pressure and flow patterns if you switch from patient to patient. In each of the settings try to optimize the ventilator settings. Assume the patient has a normal weight of 70 kg. What would be an appropriate setting in all different exercises for such a patient?

Special exercises:

When using the “active patients” (patients combined with a spontaneous breath different to “Apnea”): check the influence of pressure support on your ventilator on the time course of the respiratory cycle.

When using the spontaneous breaths exercises: check again the influence of pressure support on the tidal volume and the flow pattern of your ventilator.

What happens if you increase the resistance during the spontaneous breaths (e.g. by using endotracheal tubes of different diameter)?

Trigger

- *You will be able to learn about the concept of triggering a ventilator.*
- *You will learn the difference between pressure control of trigger and flow control of trigger.*
- *You will understand why flow control of trigger decreases the amount of breathing work in most patients.*
- *You will understand how self-triggering of respirators occur and how to avoid it.*

Trigger means that the inspiratory support of the ventilator is synchronized with the muscular activity of the patient and the wish to inhale.

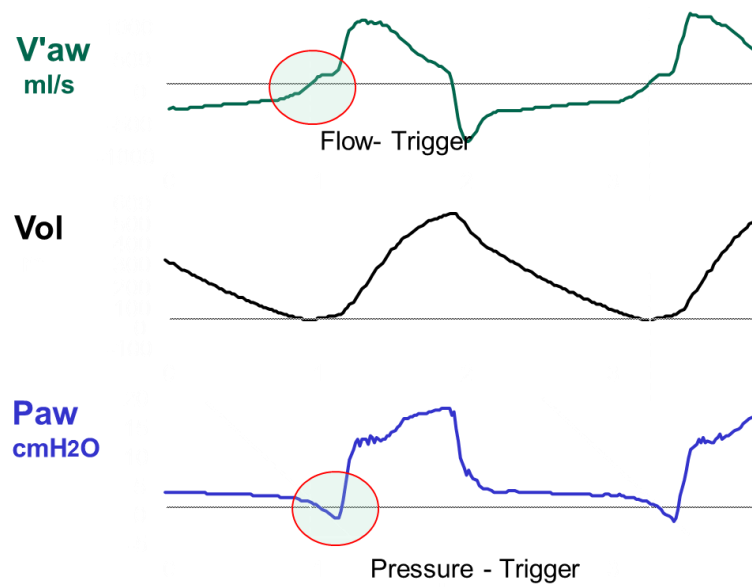
Pressure control trigger detects a drop in the pressure system of the ventilator during expiration (caused by the patient inspiration)

Flow control trigger detects a flow into the lungs at the beginning of the inspiration

All ventilators measure variables like pressure or flow and are able to start a new inspiration if a preset value (the trigger threshold) is reached. While the older time triggers are no longer present in modern machines, the most frequently used triggers are pressure (the inspiration starts if a certain pressure drop in the system occurs) or flow (the inspiration starts, if a certain inspiratory flow into the patient is detected). Flow triggering has been shown to decrease the work the patient must perform to trigger inspiration. The following graph shows the typical flow, volume and pressure curves that are used with these triggers.

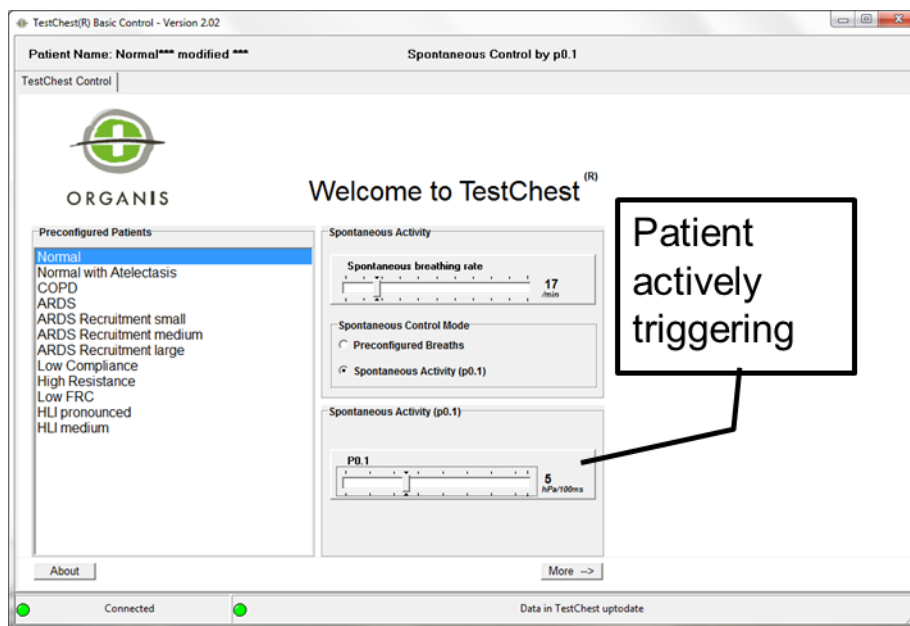
TRIGGER

Fig. 1 Graphical representation of Flow- and Pressure-Trigger:



TRIGGER

Activity:



Use the “Normal” patient. Click on “Spontaneous Activity (P0.1)”. Select a certain respiratory rate (e.g. 17/min). Select the different trigger activities, expressed by different P0.1 values.

Connect the ventilator to the TestChest and practice different modes of ventilation (e.g. volume control, pressure control). In each mode try different trigger settings (e.g. pressure trigger, flow trigger with varying sensitivities) and observe if the ventilator triggers or if self-triggering occurs.

Observe pressure and flow patterns if you switch from exercise to exercise. In each of the settings try to optimize the ventilator settings.

Compliance, Resistance

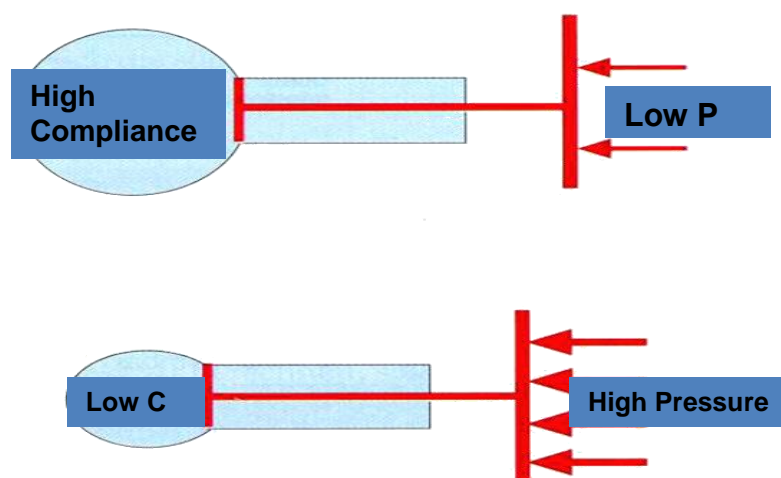
- You will be able to learn how the total compliance of the respiratory system changes the flow and pressure patterns on the respirator.
- You will understand why decreasing compliance (e.g. worsening of lung failure) may cause pressure increase in volume control or decrease tidal volume in pressure control.
- You will be able to learn about the influence of the resistance during mechanical ventilation.
- You will understand the concept of respiratory time constants and their influence on the desired settings of a ventilator.

Compliance expresses the amount of volume increase into the lungs at a given pressure change (increase).

$$C = \frac{dV}{dP}$$

The compliance is normally expressed in the units ml / cmH₂O. The normal values of the total compliances in adults range between 60 ml/cmH₂O to 120 ml/cmH₂O. Reduced values are found in all kind of lung failure. A reduced compliance of less than 30 ml/cmH₂O is one condition in the standard definition of ALI / ARDS. Assuming a total compliance of 100 ml/cmH₂O means that during ventilation using a peak pressure of 10 cmH₂O above PEEP a total of 1000 ml tidal volume will result.

Fig. 1 Graphical representation of Compliance:



COMPLIANCE, RESISTANCE

Resistance is the pressure needed to drive a certain flow (Ohm's law).

$$R = \frac{dP}{dV/dt}$$

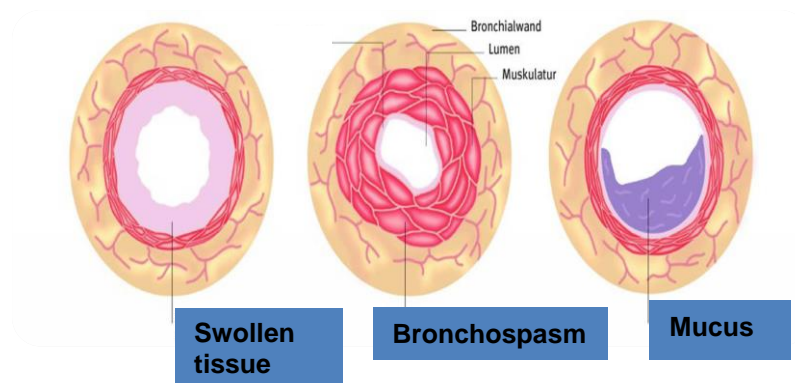
Resistance is normally expressed in the units $\text{cmH}_2\text{O} \cdot \text{sec} / \text{ml}$

The resistance increases with 4th power of the diameter (radius) of the bronchial system (Hagen-Poiseuille's Law). Frequent causes of reduced bronchial diameter in ventilated patients are:

- Swollen tissue
- Bronchospasm
- Mucus

The normal values of the bronchial resistance in adults range between 3-6 $\text{cmH}_2\text{O} \cdot \text{sec} / \text{ml}$. In intubated patients the resistance depends very much on the size of the ET. Values between 6-12 $\text{cmH}_2\text{O} \cdot \text{sec} / \text{ml}$ are frequently found.

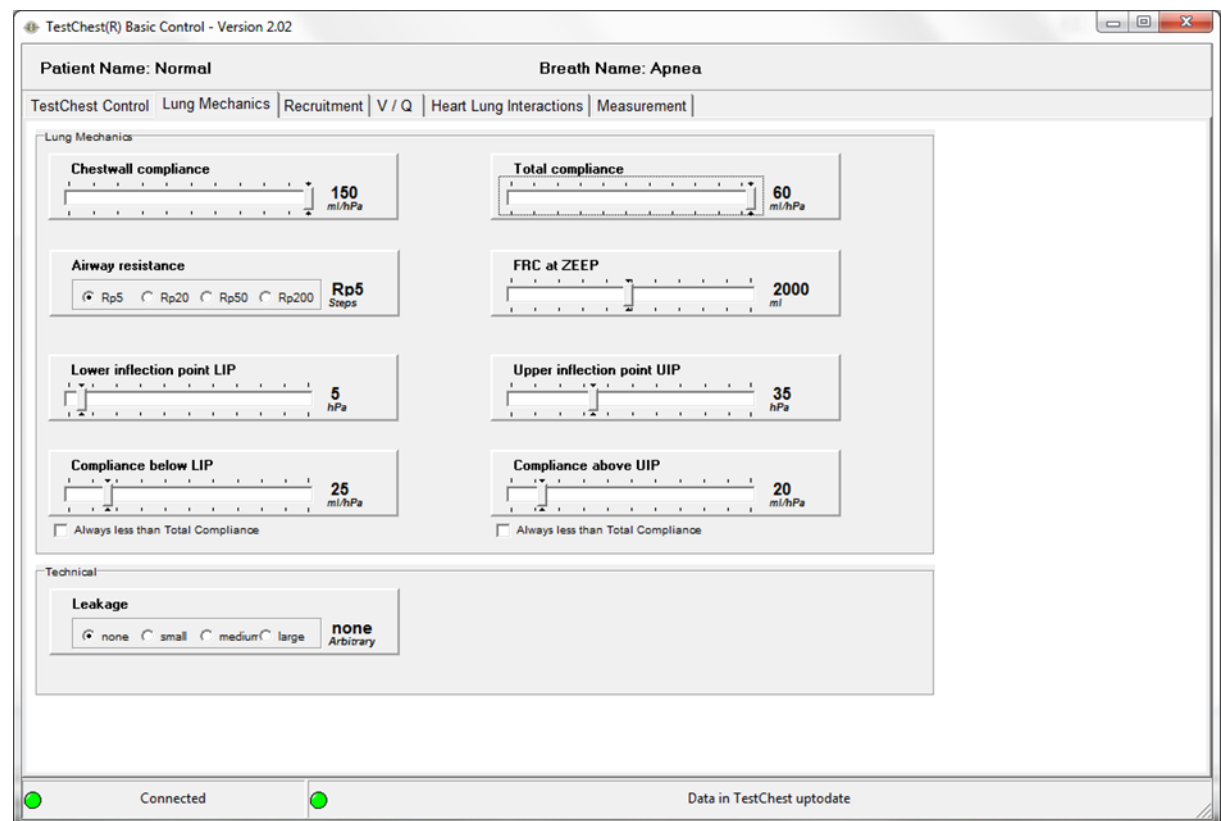
Fig. 2 Frequent causes of elevated resistance



COMPLIANCE, RESISTANCE

Activity

In the basic software open the page “Lung Mechanics”.



Make adjustments to “Total compliance” and “Airway resistance”.

Connect the TestChest to a ventilator and observe the various parameters when you change the mechanical properties of the TestChest.

Refer also to the next chapter, where you learn more details about the relationship between compliance and resistance.

Time Constants

- *You will understand the concept of respiratory time constants and their influence on the desired settings of a ventilator.*
- *You will understand the concept of Auto-PEEP*
- *You will experience with different time constants and adapt the ventilator settings to avoid Auto-PEEP*

The understanding of time constants is especially important in situations with high resistance or if the respiratory rate is set too high on the ventilator or if the expiration time is too short to allow a full expiration of the patient.

The **Time Constant** of the lung (TC) is a concept borrowed from electrical engineering which describes the phenomenon whereby a given percentage of a passively exhaled breath of air will require a constant amount of time to be exhaled regardless of the starting volume given constant lung mechanics. At the start of exhalation, the initial flow of gas out of the lung depends upon the driving pressure (i.e. alveolar pressure - mouth pressure) and it depends on the airway resistance. For any given volume of gas, the alveolar pressure at the start of exhalation is only dependent upon the lung compliance. Mathematically, the time constant is defined as compliance multiplied by the airway resistance and the resulting value has units of seconds of time

Time Constant is the product of compliance and resistance.

$$\tau = R * C$$

The unit is seconds.

Normal values range between 0.5 and 1 sec. In intubated and ventilated patients the expiratory time constant is frequently somewhat higher than the inspiratory time constant. This results from an increased resistance of the airways during expiration and the resistance that is added to the entire system by the expiratory valve of the ventilator. The following graph shows that approximately 2-3 time constants are necessary to fully inflate or deflate the lung volume.

TIME CONSTANTS

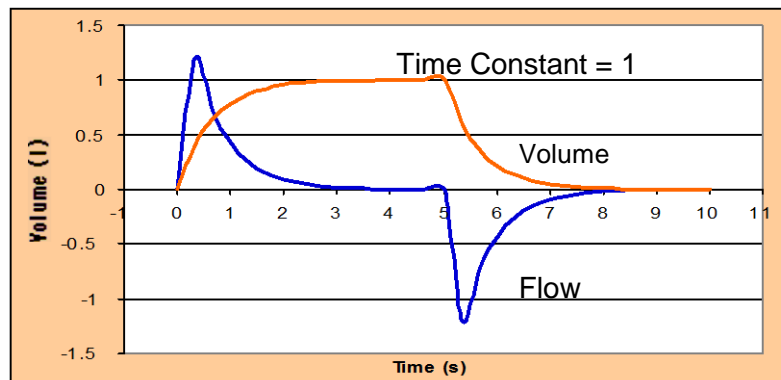


Fig. 1 Representation of Volume and Flow assuming a time constant of 1

The concept of the time constants is important to avoid Auto-PEEP. Auto-PEEP occurs, if the expiratory time of the ventilator cycle is shorter than 3 time constants of the total respiratory system. It can be monitored by observing the flow pattern on the respirator: if the flow curve ends below zero when the next inspiration takes place, the expiration time is too short for a full lung deflation.

In normal exhaling the expiratory flow curve will meet the zero-axis at its end (Fig. 2).

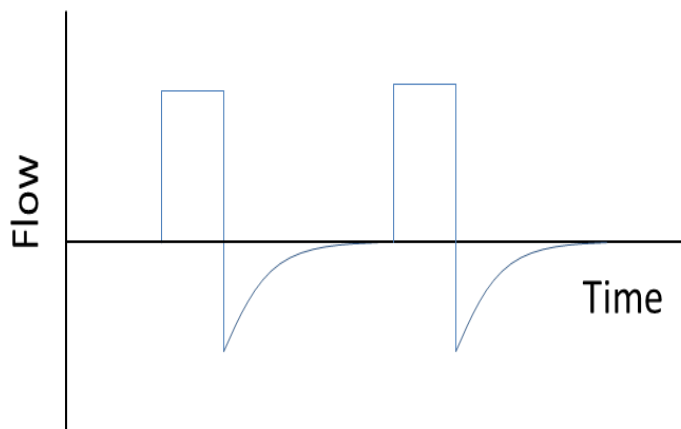


Fig. 2 Flow pattern during expiration reaches zero → no Auto-PEEP

In patients with incomplete emptying areas the expiratory flow curve does not hit the zero-axis anymore (Fig. 3).

This resting volume according to incomplete emptying is called Auto- or Intrinsic PEEP (PEEPi). Auto PEEP is the popular name used to describe increased alveolar pressure caused by gas trapping during mechanical ventilation. Gas trapping occurs when there is inadequate time to exhale the mechanical tidal volume.

TIME CONSTANTS

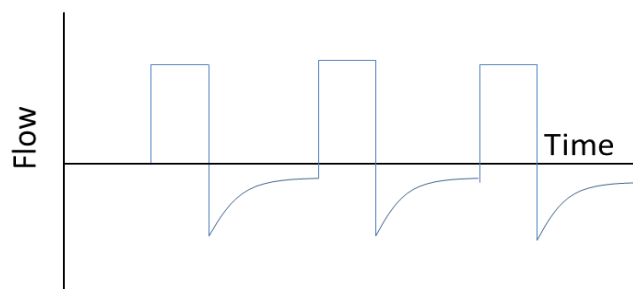


Fig. 3 Flow does not reach zero during expiration. This is a clear hint that Auto-PEEP occurs.

Recall that the time constant determines the length of time needed for a passive exhalation and that the time constant is the product of airway resistance and lung compliance. The lower the compliance, the higher the driving pressure pushing gas out of the lungs during exhalation; the lower the resistance, the higher the expiratory flow rate can be when driven by the alveolar pressure.

Activity:

Select the Normal Patient and no spontaneous breathing (select “Apnea” or put the P0.1 to zero). Open the tabsheet “Lung Mechanics”.

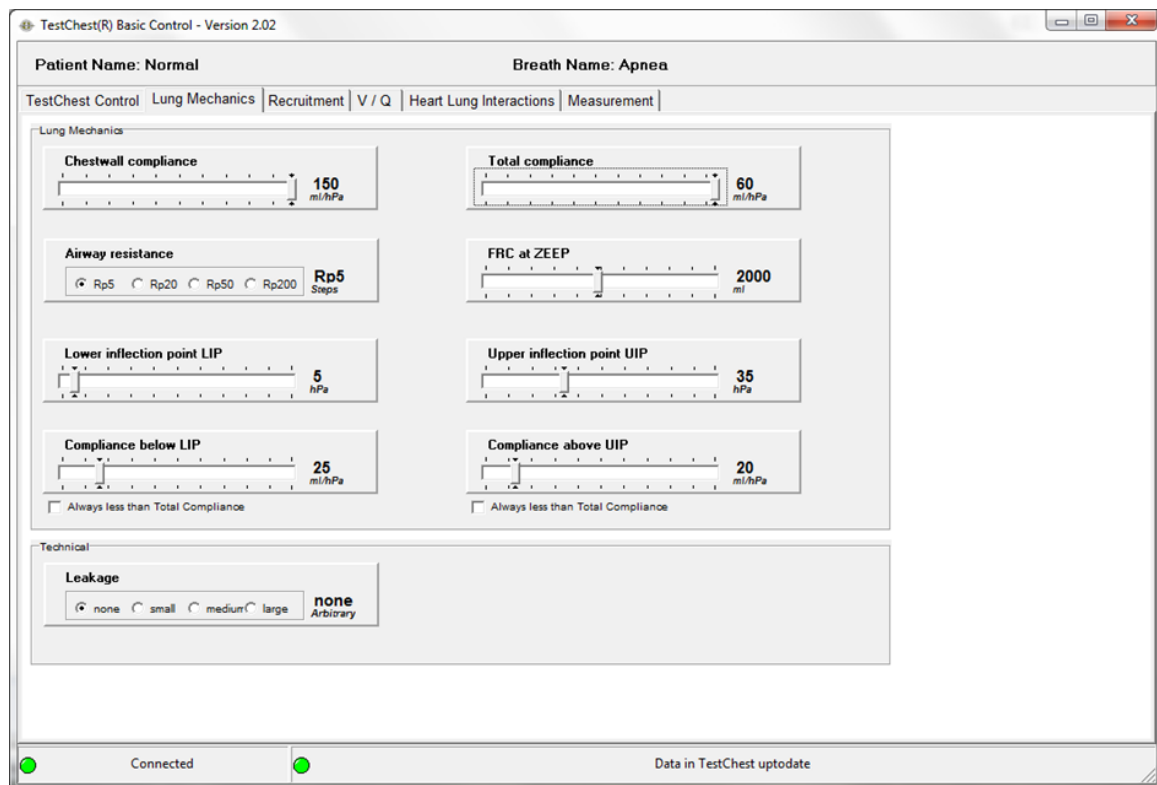
We will use 3 different time constants:

Normal RC, Low RC and High RC.

Select the values according to the following table:

	Total Compliance [ml/cmH ₂ O]	Airway resistance [Rp Value]	Estimated Time constant [sec]
Normal RC	40	Rp20	0.8
Low RC	30	Rp 5	0.2
High RC	60	Rp 50	3

TIME CONSTANTS



Select the 3 different time constants step by step. Each step will set the TestChest into a certain mode which can now be experienced by various respirator settings.

Connect the ventilator to the TestChest use e.g. volume control or pressure control and practice I:E settings as well as different respiratory rates. Observe the flow curve and observe the occurrence of Auto-PEEP. Determine the time constants that are set in the 3 different states.

Dead Space

- *Dead space is the volume of tidal ventilation that does not take part in the gas exchange process.*
- *You will learn the effects of tidal volume / minute volume and variable dead spaces on the endtidal CO₂ (representing the arterial CO₂).*
- *You will understand why it is important to minimize the external dead space in artificial ventilation.*
- *You will work with various ventilator settings and 3 different sizes of the internal TestChest dead space.*

Dead space is the volume of air which is inhaled that does not take part in the gas exchange, either because it (1) remains in the conducting airways, or (2) reaches alveoli that are not perfused or poorly perfused.

About a third of every resting breath has no change in O₂ and CO₂ levels. In adults, it is usually in the range of 150 mL.

Dead space can be increased (and better envisioned) by breathing through a long tube, such as a snorkel. Even though one end of the snorkel is open to the air, when the wearer breathes in, they inhale a large quantity of carbon dioxide that remained in the snorkel from the previous exhalation. Thus, a snorkel increases the person's dead space by adding even more "airway" that doesn't participate in gas exchange.

The **total dead space** (also known as physiological dead space) is the sum of the anatomical dead space plus the alveolar dead space.

Anatomic dead space

Anatomical dead space is that portion of the airways (such as the mouth and trachea to the bronchioles) which conducts gas to the alveoli. No gas exchange is possible in these spaces.

Alveolar dead space

Alveolar dead space is sum of the volumes of those alveoli which have little or no blood flowing through their adjacent pulmonary capillaries, i.e., alveoli that are ventilated but not perfused, and where, as a result, no gas exchange can occur.

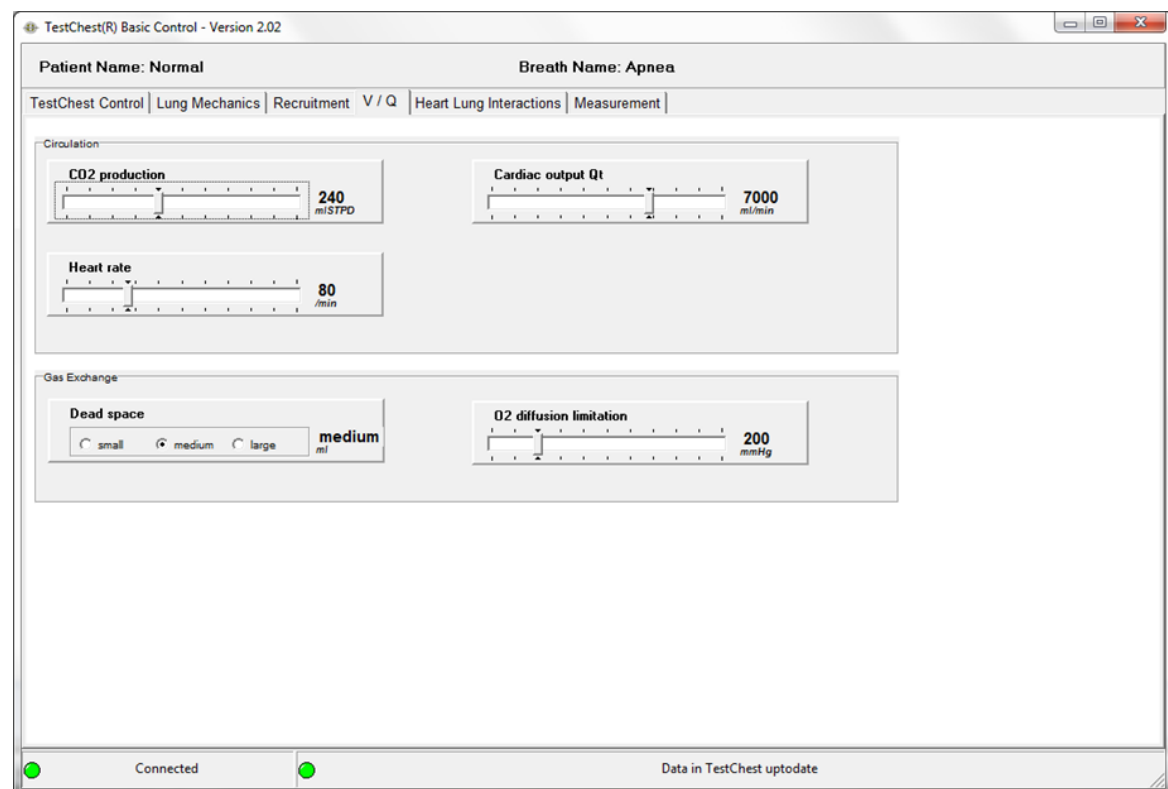
DEAD SPACE

Activity:

Step 1: Select the page V/Q and increase the CO₂ production to 350 ml. This will make the effects of the dead space more pronounced.

Step 2: Connect a ventilator to the TestChest and measure end expiratory CO₂ (e.g. by main stream capnometer).

Step 3: Select the 3 different levels of dead space (small, medium, large) and observe the behavior of the expired CO₂ concentration. Vary the tidal volume and observe how this influences the CO₂ excretion.



Change the tubing between the Y-piece and the endotracheal tube to add external deadspace to the system and repeat the various settings.

Inflection Points

- *Inflection Points can be found in the pressure-volume-loop during mechanical ventilation.*
- *You will learn how to detect inflection points during artificial ventilation*
- *You will understand what the lower and upper inflection points mean for the optimization of artificial ventilation, e.g. adjust PEEP and end inspiratory pressure levels.*

Inflection points can be shown in the pressure-volume-loop during artificial ventilation

Special maneuver or super syringe is used to display the course of the pressure-volume-loop

The **lower inflection point** is related to the full opening of the lung

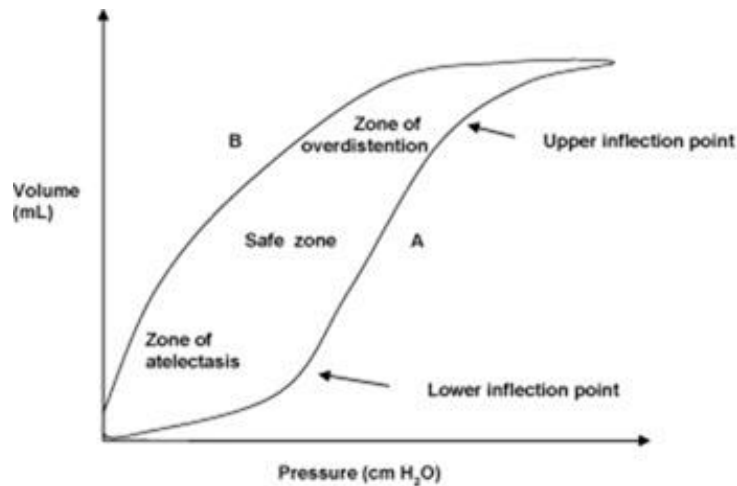
The **upper inflection point** is correlated to a pressure volume relationship where over distension and over inflation takes place.

It is commonly assumed that optimal ventilation settings should be between lower and upper inflection points.

Inflection points in the pressure-volume-loop of the lung during ventilation can be determined with various methods. The most common method is the so call “super syringe” where the lung is inflated with a big syringe stepwise.

State of the art respirators can generate pressure-volume-loops by slowly inflating the lung using a pressure ramp. In the following graph these inflections points are shown:

INFLECTION POINTS



It can be assumed that the optimal range of ventilation is between the lower and upper inflection point. At least the compliance should be greater in this range compared to the total compliance if this range is extended.

While a lower inflection point may always be visible at pressures between 0 and 10 cmH₂O, the upper inflection point may only be visible if either high pressures are used or in certain pathologies of the lung like ARDS.

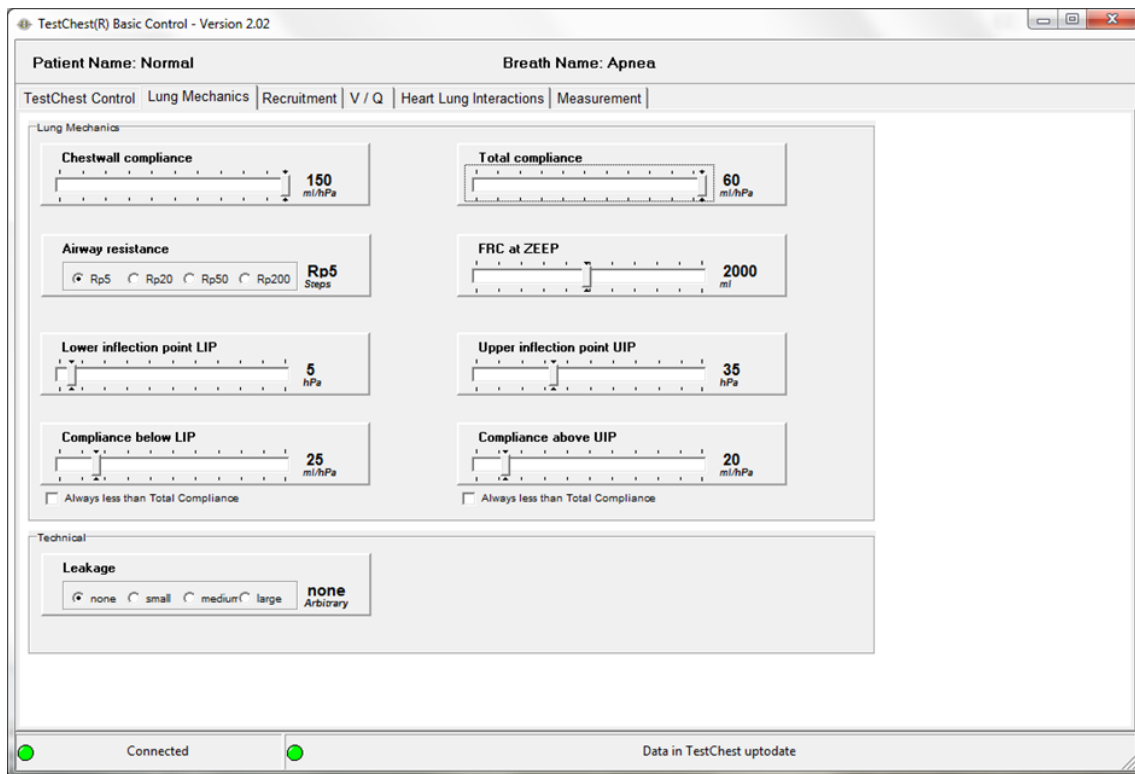
A more detailed description will be found in the learning module ARDS.

INFLECTION POINTS

Activity:

Open the tabsheet “Lung Mechanics” and adjust the controls like in the following picture.

Connect the TestChest to a ventilator. If possible: record a pressure-volume-loop with the ventilator. Observe the resulting curves. They should be similar to the theoretical curve given above.



You may make the effects more pronounced by the following settings:

- LIP to 10
- UIP to 25
- Compliance below LIP to 10
- Compliance above UIP to 15

Leakage

- *Leakage is frequently observed during artificial ventilation.*
- *You will learn how to detect even small amounts of leakage with different methods.*
- *You will be able to adjust ventilator settings if pleural fistula is present.*
- *You will learn about the consequences of ventilator settings on the amount of air passing through the fistula.*

Leakage in artificial ventilation is presented as a difference between inspiratory and expiratory tidal volume.

Leakage can occur:

- In the technical ventilator system (leakage of tubings)
- At the cuff level of the intratracheal tube or cannula
- As a broncho-pleural fistula, mostly leading to pneumothorax

The most common reason for any kind of leakages during ventilation are leakages occurring in the technical system of the ventilator or in the tubings or even in the tightness of the endotracheal cuff.

Normally these kind of leakages lead to a significant loss of volume, i.e. that the expired volume is substantially smaller than the inspired volume.

Inside the lung the situation is much more complicated:

Air leaks can be defined as any extrusion of air from normal gas-filled cavities including the upper airway, sinuses, tracheobronchial tree, and gastrointestinal (GI) tract. Clinical conditions of relevance in anaesthesia and critical care include

- Pneumothorax
- Pneumomediastinum
- Pneumopericardium
- Pneumoperitoneum
- Subcutaneous emphysema.

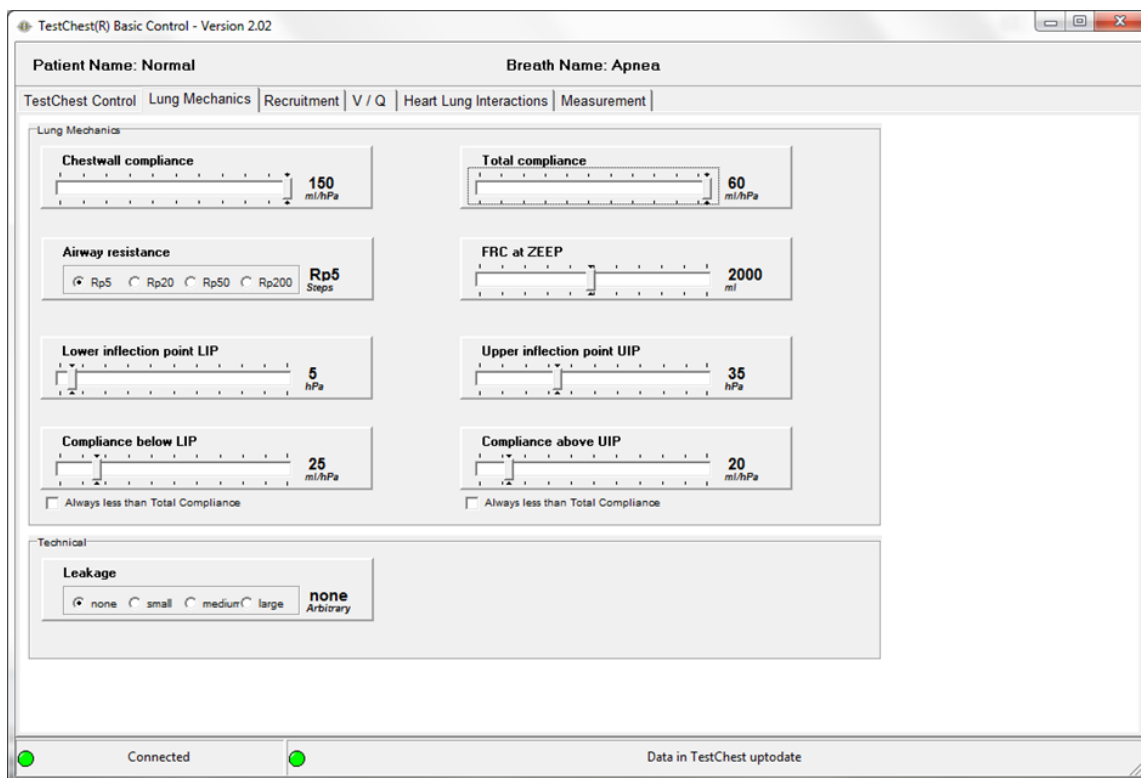
An estimated 4–15% of critically ill patients on ventilators develop barotrauma, manifesting as abnormal air collections in the chest. Underlying lung disease, such as pneumonia and especially ARDS, increases the risk significantly. The major factors associated with development of barotrauma include a peak inspiratory pressures >40 cm H₂O, the use of positive end-expiratory pressure (PEEP), and an inappropriately large tidal volume.

LEAKAGE

Activity:

TestChest has 3 different levels of air leakage: small, medium, large. The total amount can also be adjusted with a little screw in front of the TestChest (please refer to the instruction manual).

Open the page „Lung Mechanics“. The leakage can be set to „none“ or to one of the 3 different levels.



Make up your mind what would be the best settings for the given situation.

Connect the ventilator to the TestChest and practice different modes of ventilation (e.g. volume control, pressure control). Observe in- and expiratory tidal volumes as an objective measure about the level of leakage.

Noninvasive Ventilation (NIV)

- *You will be able to learn about the concept of noninvasive ventilation.*
- *You will learn how to ventilate a postoperative patient noninvasively.*
- *You will understand which limitations may occur due to NIV.*

Noninvasive ventilation (NIV) refers to the administration of ventilatory support without using an invasive artificial airway (endotracheal tube, tracheostomy tube or any kind of supraglottic device).

Inclusion criteria NIV:

- Patient cooperation (an essential component that excludes agitated, belligerent or comatose patients)
- Dyspnea (moderate to severe, but short of respiratory failure)
- Tachypnea (>24 breaths/min)
- Increased work of breathing (accessory muscle use, pursed-lips breathing)
- Hypercapnic respiratory acidosis (pH range 7.10-7.35)
- Hypoxemia ($\text{PaO}_2/\text{FIO}_2 < 200$ mm Hg, best in rapidly reversible causes of hypoxemia)

Noninvasive ventilation (NIV) refers to the administration of ventilatory support without using an invasive artificial airway (endotracheal tube, tracheostomy tube or any kind of supraglottic device). The use of noninvasive ventilation has markedly increased over the past two decades, and noninvasive ventilation has now become an integral tool in the management of both acute and chronic respiratory failure, in both the home setting and in the critical care unit. Noninvasive ventilation has been used as a replacement for invasive ventilation, but its flexibility also allows it to be a valuable complement in patient management.

Positive-pressure ventilation delivered through a mask has become the predominant method of providing noninvasive ventilatory support. Early bedside physiologic studies in healthy patients and in patients with respiratory conditions document successful ventilatory support (i.e., reduction in respiratory rate, increase in tidal volume, decrease in dyspnea) with reduction in diaphragmatic electromyography (EMG), transdiaphragmatic pressures, work of breathing and improvement in oxygenation with a reduction in hypercapnia.

Ventilatory support can be achieved through a variety of interfaces (mouth piece or nasal, face, or helmet mask), using a variety of ventilatory modes (volume ventilation [CMV], pressure support [PSV], bilevel positive airway pressure [BIPAP/DUOPAP], proportional-assist ventilation [PAV], continuous positive airway pressure [CPAP]) with either ventilators dedicated to noninvasive ventilation (NIV) or those capable of providing support through an endotracheal tube or mask.

NONINVASIVE VENTILATION

Older models of noninvasive ventilators required oxygen to be bled into the system, but current models incorporate oxygen blenders for precise delivery of the fraction of inspired oxygen (FIO₂).

The key to the successful application of noninvasive ventilation is in recognizing its capabilities and limitations. This also requires identification of the appropriate patient for the application of noninvasive ventilation (NIV).

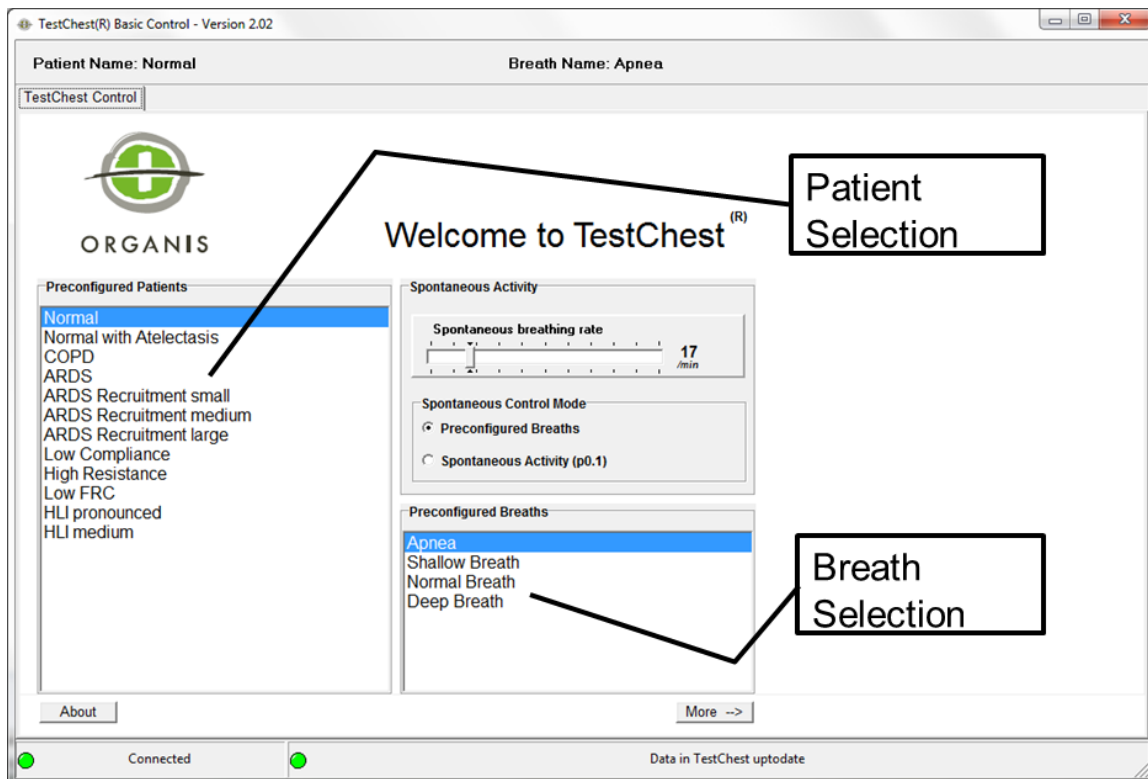
Material:

For this exercise at least the following materials are needed:

- TestChest
- Intubation Head with acceptable noninvasive face mask
- Ventilator with NIV option
- Alternatively special ventilator for noninvasive ventilation

Activity:

You are going to practice “Noninvasive Ventilation after Extubation”.



Interest in the use of noninvasive ventilation (NIV) after discontinuation of mechanical ventilation is considerable. Postextubation respiratory insufficiency requiring reintubation can occur in more than 20% of patients.

NONINVASIVE VENTILATION

Connect an intubation head to the TestChest and select an appropriate face mask.

Select “Normal” patient and “Normal Breath”. Put the ventilator on CPAP plus pressure support. Check different settings and different support pressures. Switch the TestChest to “Shallow Breath”. Observe again the different settings.

Use the “ARDS” patient and repeat the above settings. You will reach limitations of noninvasive ventilation.

Finally repeat the exercise with the COPD patient. Noninvasive ventilation is state of the art in COPD!

Refer also to the chapter “Noninvasive Ventilation” in the Learning Module “Basics of Artificial Respiration”.

COPD

- *You will be able to learn how the respiratory resistance influences the flow and pressure patterns on the respirator.*
- *You will understand why COPD patients need low respiratory frequencies set on the respirator. Musculature weakness worsens the situation and leads to respiratory failure.*
- *You will be able to learn about noninvasive ventilation in COPD and its limitations.*
- *You will understand the concepts of invasive ventilation in COPD and the optimal adjustment of the ventilator.*

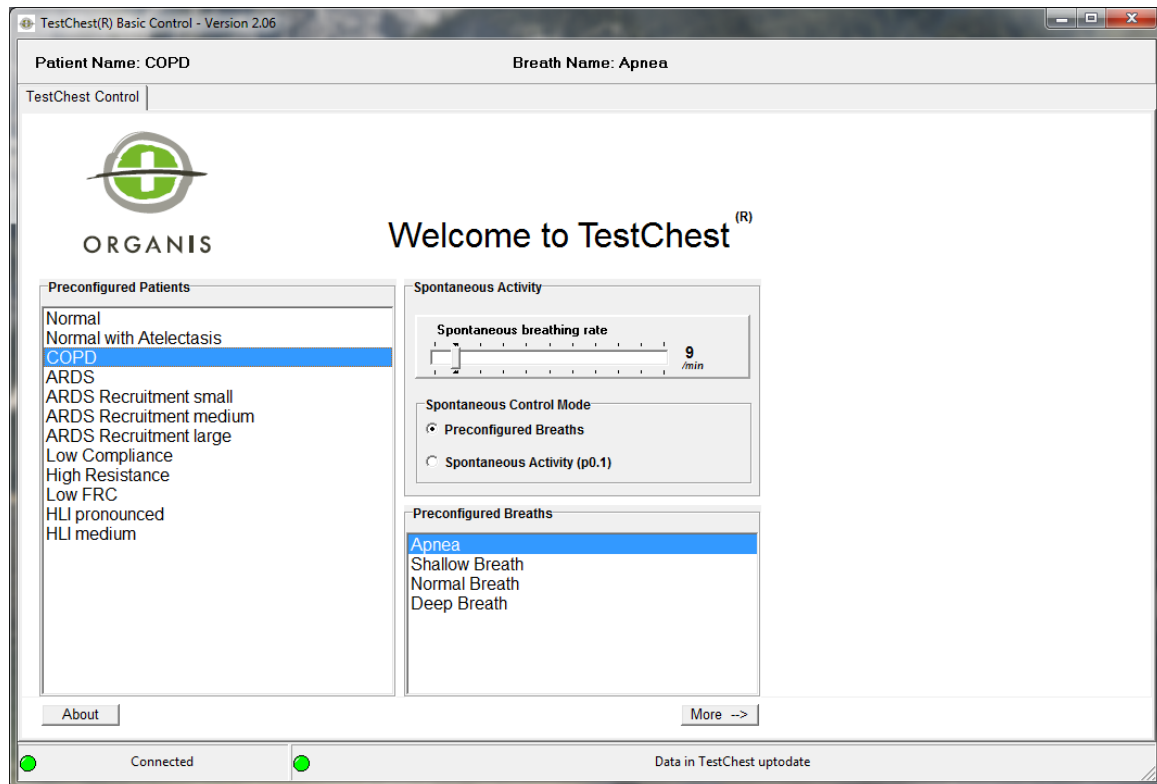
Chronic obstructive pulmonary disease (COPD) is also known as chronic obstructive lung disease (COLD), chronic obstructive airway disease (COAD), chronic airflow limitation (CAL) and chronic obstructive respiratory disease (CORD).

COPD is a lung disease defined by persistently poor airflow as a result of breakdown of lung tissue (known as emphysema) and dysfunction of the small airways.

More details can be found in the Learning Module “COPD”

Activity:

Select the COPD patient. Connect the TestChest to a ventilator and try to find out optimal settings for this patient. Look at the other tabsheets to find out how this patient has been modeled (after selecting a certain patient, all controls are set to those values with which the patient has been created).



Try different modes of ventilation (e.g. volume control, pressure control). Observe pressure and flow.

Repeat these exercises also with noninvasive ventilation.

ARDS: Protective Ventilation

- *ARDS is one of the most important causes to ventilate a patient.*
- *You will learn the most important element of respiratory treatment*
- *You will understand how low compliance influences the respiratory patterns.*

ARDS (Acute Respiratory Distress Syndrome) has first been described in 1967 by Ashbaugh and colleagues.

Definition

- Acute lung injury with acute onset
- Thorax X-ray shows diffuse lung infiltrations
- Reduced compliance ($< 30 \text{ ml/cmH}_2\text{O}$)
- Horowitz Index ($\text{paO}_2 / \text{FiO}_2$) below 300
- Cardiogenic failure excluded

ARDS: Degree of Severity (Berlin Definition 2012)

Mild ARDS	Horowitz 201-300 at PEEP $\geq 5 \text{ cmH}_2\text{O}$
Moderate ARDS	Horowitz 101-200 at PEEP $\geq 5 \text{ cmH}_2\text{O}$
Severe ARDS	Horowitz ≤ 100 at PEEP $\geq 5 \text{ cmH}_2\text{O}$

People with acute respiratory distress syndrome (ARDS) are by definition severely hypoxemic, and nearly all require invasive mechanical ventilation.

Yet mechanical ventilation itself can further injure damaged lungs (so-called ventilator-induced lung injury); minimizing any additional damage while maintaining adequate gas exchange ("compatible with life") is the central goal of mechanical ventilation in ARDS.

Benefits of Low Tidal Volume Ventilation in ARDS

Low Tidal Volume Ventilation (LTVV) reduces the damaging, excessive stretch of lung tissue and alveoli (so-called volutrauma), and is the standard of care for people with ARDS requiring mechanical ventilation. Although ARMA, the largest clinical trial supporting this paradigm, was criticized both for its design and for ethical concerns, its results (published in 2000 by ARDSNet), followed by two flawed but concordant meta-analyses including ten randomized trials total, have convinced most intensivists that using low tidal volumes improves

survival for people with ARDS. Taken together, the trials suggest that a strategy of low tidal volume ventilation (6-8 mL/kg ideal body weight) reduces absolute mortality by about 7-9%, as compared to using ≥ 10 mL/kg tidal volumes (~42% mortality in control groups vs. ~34% in the LTVV groups). This translates to a “number needed to treat” of between 11-15 people with ARDS to prevent one death by using LTVV.

How to use Low Tidal Volume Ventilation in ARDS

The protocol from the ARMA trial can serve as a guide to perform low tidal volume ventilation for mechanically ventilated patients with ARDS:

- Start in any ventilator mode with initial tidal volumes of 8 mL/kg predicted body weight in kg, calculated by: $[0.9 \times (\text{height in cm}) + 45.5 \text{ for women or } + 50 \text{ for men}]$.
- Set the respiratory rate up to 35 breaths/min to deliver the expected minute ventilation requirement (generally, 7-9 L/min)
- Set positive end-expiratory pressure (PEEP) to at least 5 cmH₂O (but much higher is probably better), and FiO₂ to maintain an arterial oxygen saturation (SaO₂) of 88-95% (paO₂ 55-80 mmHg). Titrate FiO₂ to below 70% when feasible (though ARDSNet does not specify this).
- Over a period of less than 4 hours, reduce tidal volumes to 7 mL/kg, and then to 6 mL/kg.

Permissive Hypercapnia in ARDS

This single-minded focus on reducing plateau pressures derives from the likely survival benefit from low tidal volume ventilation and low plateau pressures observed in clinical trials (or if you prefer, the harmful effects seen from using “normal” or physiologic tidal volumes with resulting high plateau pressures in those trials).

Achieving these low plateau pressures usually requires tidal volumes low enough to result in hypoventilation, with resulting elevations in pCO₂ and respiratory acidemia that can be severe and to the treating physician, anxiety-provoking. This approach, “permissive hypercapnia,” represents a paradigm shift from previous eras, in which achieving normal blood gas values was the main goal of mechanical ventilation.

How “permissive” can one be? Mechanically ventilated patients with ARDS appear to tolerate very low blood pH and very high pCO₂ values without any adverse sequelae (defying physicians’ anxieties based on intuition, training and medical lore):

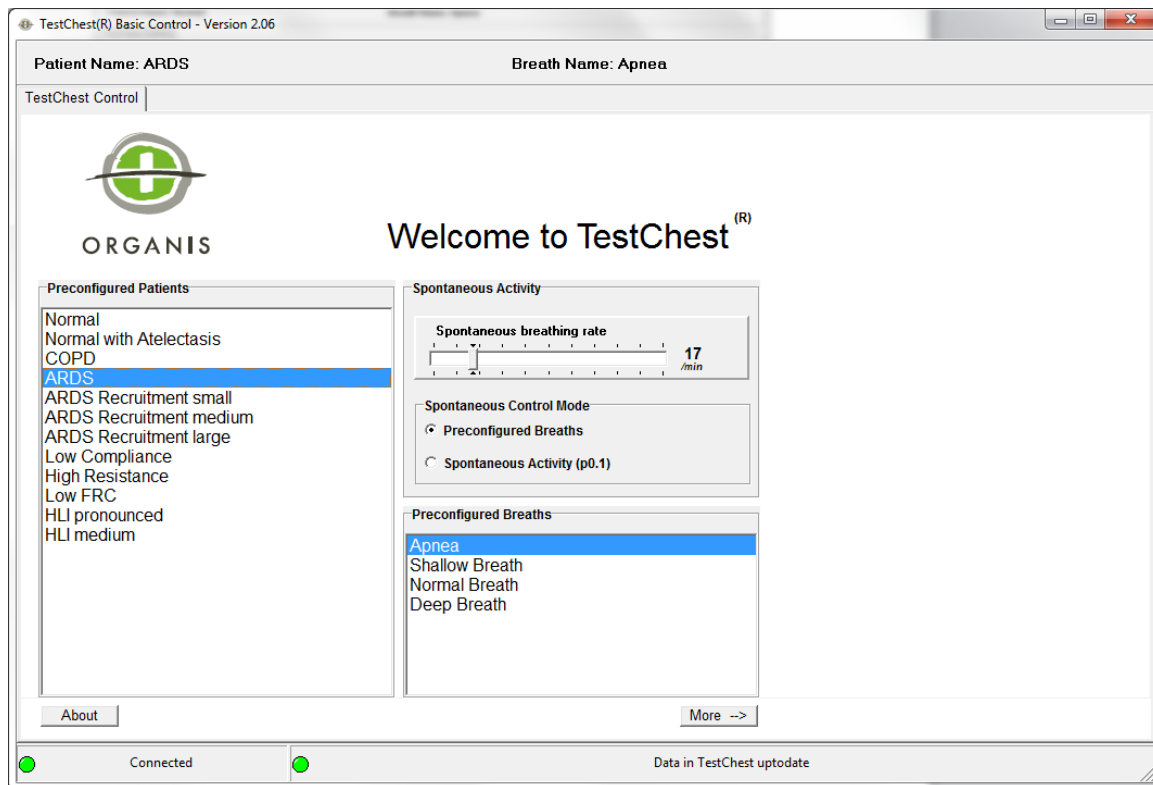
Current consensus suggests it is safe to allow pH to fall to at least 7.20. The actual pCO₂ is of little importance. When pH falls below 7.20, many physicians choose to administer sodium bicarbonate, Carbicarb or THAM to maintain blood pH between 7.15 – 7.20.

More details in the learning module “ARDS”

Activity:

For this exercise you should use the SpO₂ simulator and an appropriate monitor.

Select patient “ARDS” and set the ventilator to protective ventilation, given the patient has an ideal body weight of 70 kg.



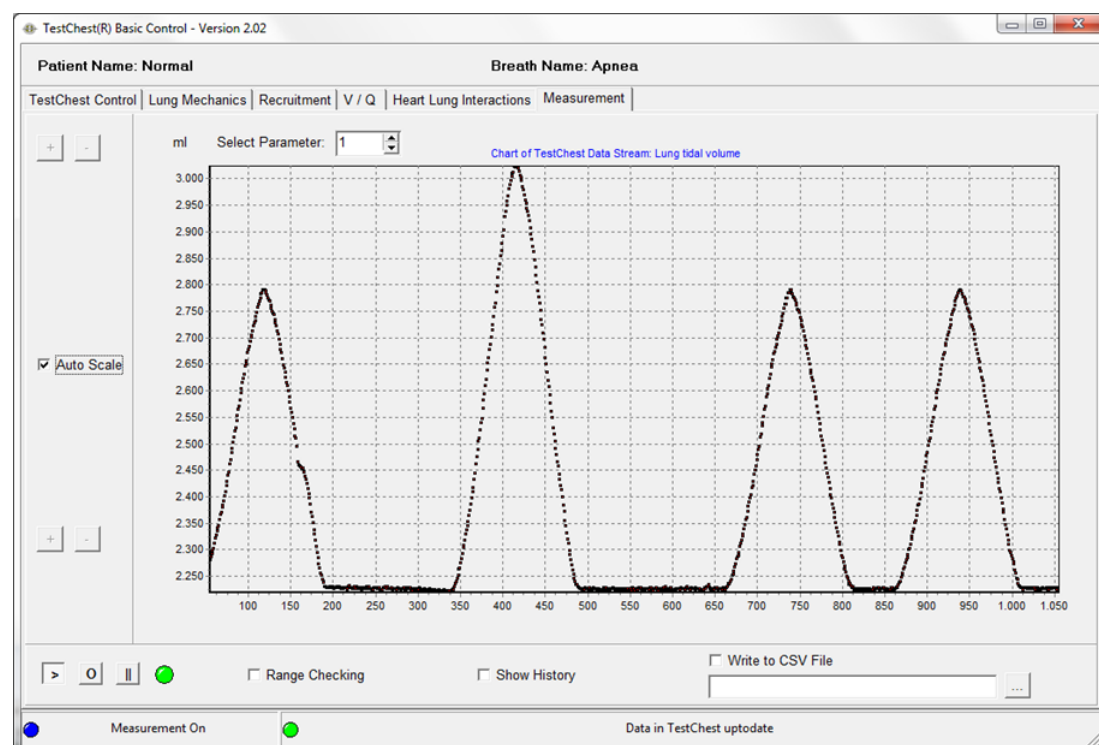
Use different PEEP settings and observe the SpO₂. Repeat different settings of PEEP with the 3 different ARDS patients. Observe how they can be recruited with higher PEEP thus improving the gas exchange.

Measurement:

TestChest also provides Measurement data. In the Basic Software you can watch the following values in online-graphs:

- Flow in ml/s
- Lung tidal volume in ml
- p alveole in hPa
- Airway pressure in hPa
- Bellows position in cm
- Intrapleural pressure in hPa
- Cardial pressure in hPa
- Fraction of O₂ inspiratory in %
- Ambient pressure in hPa
- Temperature in °Celsius
- FRC actual in ml,
- Shunt fraction in %
- Partial pressure O₂ air chamber in Torr
- Partial pressure O₂ effective in Torr
- Oxygen saturation pulmonary capillaries in %

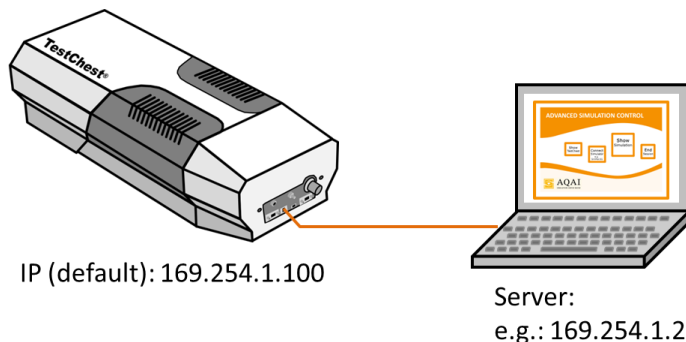
Open the page „Measurement“. Select the desired parameter. Click on „>“ to start the recording. Please refer to the TestChest manual for more details.



LAN Setup

TestChest can be connected directly to your PC. Just check that your PC is in the same IP-address-range as the TestChest. The TestChest default IP is **169.254.1.100**. To check/change the IP-address of your computer, run a windows command shell (cmd.exe and enter "ipconfig") or use the System Control Panel "Network and Sharing Center". For further details check the PC Manual or the Windows Help Desk and take a look at the TestChest manual.

Hardware setup, IP-Configuration



ATTENTION:

The correct communication IP-address of the TestChest must be set in the Basic Software -> Manual: Operating instructions TestChest V2.

The IP-address of TestChest can be changed, please check that all devices are in the new correct IP-address-range.

If in doubt: Use the "Ping" command on the server PC to check that all devices can be reached by the TCP/IP connection.

E.g. to check the TestChest:

Open a CMD Window on the server.

At the prompt type "ping 169.254.1.100" and ENTER

The result will show, if the TestChest is reachable or not.