Lung Simulator Training Parameters

Sponsored Content by neosim AG Jun 17 2020

Optimizing respiratory therapy in intensive care is a challenge for clinicians at all levels of expertise. As the degree of illness increases, so do the difficulties in administering respiratory therapy, and along with that rises the associated morbidity and mortality.

Simulation-based training is a promising area in which to improve the learning curve and to explore the management of challenging and rare respiratory illnesses. During simulation sessions, patient decompensation can be simulated and therapies can be carried out without risking the wellbeing of a real patient, as well as posing a risk-free learning environment for clinicians too.

In contrast to other simulators, autonomous simulators do not require operators to generate vital signs because the simulator generates them in real-time, based on the physiological parameters that were set to define patient cases. Unfortunately, it is not easy to find values for those parameters in literature, but this article intends to fill that gap.

The fundamental set of parameters

The simulation of respiratory failure necessitates a minimal set of parameters to allow autonomous simulators to work. Typically, it is good for trainees to understand patient situations that aren’t complicated by respiratory failure before they move forward, and as such, the set of parameters available to respiratory simulators also needs to cover normal, healthy lung states.

The following table provides a list of the parameters used to simulate respiratory cases:

- Total respiratory compliance (Crs)
- Lung compliance (CL)
- Chest wall compliance (Cw)
- Compliance above the upper inflection point (Cend)
- Airways resistance (Raw)
- Airways dead space (Vdaw)

- Functional Residual Capacity (FRC)
- CO_2 production
- Oxygen uptake.

Values for all of these parameters need to be known for normal lung states and also for the two predominant respiratory problems intensive care units (ICUs) are facing at the moment: acute respiratory distress syndrome (ARDS) and chronic obstructive pulmonary disease (COPD).

What predicts the value of a lung function parameter?

It seems logical to utilize actual body measurements such as height and weight to calculate lung parameters. Unfortunately, this doesn't often work in practice, as eating habits and weight accumulation put a large frame around a fragile body. As a result, predicted body weight (PBW) instead of actual body weight must be used. There are numerous formulas to calculate PBW, and there is a preference for a certain PBW formula for use in intensive care applications [8].

However, the following simplified formula provides values accurate to 1 percent of the recommended formula:

PBW in women: height – 100 cm, subtract 10%, subtract 5

- Example of a 172 cm woman: 172-100=72, 72-7.2=65, 65-5=60 kg PBW

PBW in men: height – 100 cm, subtract 10%

- Example of a 172 cm man: 172-100=72, 72-7.2=65 kg PBW

Using the PBW, the parameters for autonomous simulators can be calculated according to Table 1.

Table 1. Predicted lung function parameters for simulation training. The number in square brackets refer to the references given below. Source: neosim AG

	Predicted normal	Predicted ARDS	Predicted COPD
Total respiratory compliance Crs	0.8 ml/mbar/kg [2,5]	0.6 ml/mbar/kg [2]	0.9 ml/mbar/kg [2]
Lung compliance CL	1.8 ml/mbar/kg [5]	1.0 ml/mbar/kg [see text]	2.4 ml/mbar/kg [see text]
Chest wall compliance Cw	1.44 ml/mbar/kg [see text]	1.44 ml/mbar/kg [see text]	1.44 ml/mbar/kg [see text]
Compliance above the UIP	8 ml/mbar [6]	8 ml/mbar [6]	8 ml/mbar [6]
Airways resistance Raw	12 mbar/(L/s) [2,5]	13 mbar/(L/s) [2]	20 mbar/(L/s) [2]
Airways dead space Vdaw	2.2 ml/kg	2.2 ml/kg	2.2 ml/kg
Functional Residual Capacity FRC	27 ml/kg [4,5,7]	17 ml/kg [1,4]	
CO_2 production	2 ml/min/kg+ 67.5 [3]	increase for sepsis	increase for WOB
Oxygen uptake	2.5 ml/min/kg+ 67.5 [3]	increase for sepsis	increase for WOB

Lung compliance (CL) and chest wall compliance (Cw) make up the total respiratory compliance (Crs) according to the formula:

$$1/Crs = 1/Cw + 1/CL$$

Because of this, only two of the compliance values can be freely chosen. The third compliance value is determined according to the formula. Due to the fact that Crs and CL are more regularly published in literature than Cw, Cw in normal lung states was calculated using the formula stated above.

Compliance that is above the upper inflection point (UIP), which can be referred to as Cend, is rarely measured. As a result, prediction formulas are not often available. To estimate Cend, the formula of Venegas et. al. has been used to generate typical pressure-volume (pV) curves published by Harris et.al.

Figure 1 shows two pairs of data. The original Venegas equation with the original parameters can be seen on the left, and on the right a more realistic pV curve, where the total lung capacity was reduced to 1500 ml above FRC and the lower and upper inflection points were moved to 4 mbar and 16 mbar, can be seen. The top curves illustrate the pressure-volume curves, and the bottom curves demonstrate the local compliance dV/dp, with dp as 10 mbar.

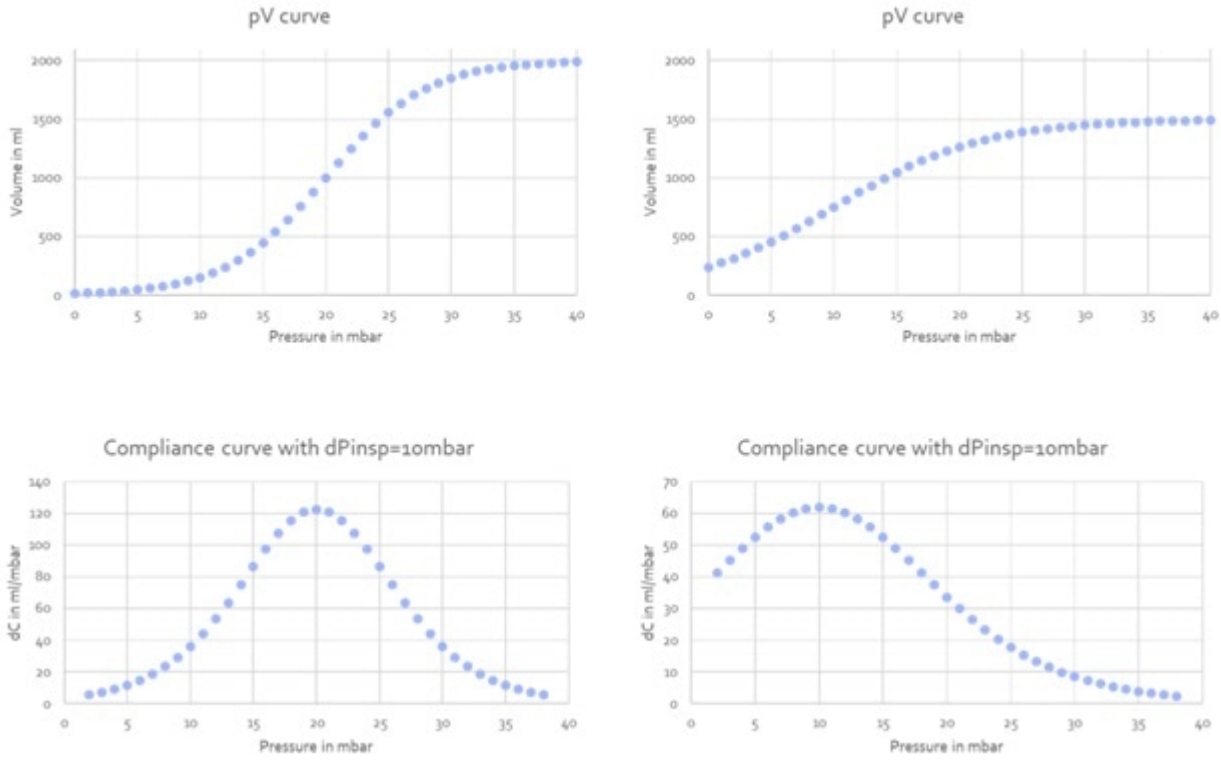

Figure 1. *Pressure-volume curves created by the Venegas equation (top row) and its the first derivative dp/dV, i.e. compliance distribution to create those curves (bottom row). Left two panels: original Venegas parameters. Right two panels: parameters set to create a typical pressure-volume curve measured in patients. Image Credit: neosim AG*

In the original Venegas equation, compliance shifts from approximately 5 to 120, and inflection points are plainly visible. As seen on the right, the more realistic curve shows compliance changing from 2 to 62, but the inflection points are almost invisible. The point that can be derived from these two sets of curves is that inflection points are not clearly visible unless the compliance difference along the curve is made to vary dramatically. For example, in TestChest (Organis GmbH, Landquart, Switzerland), the compliance above and below the inflection points should be set to <10 ml/mbar.

Making parameters to represent diseases

Aside from normal values, Table 1 also shows predicted parameter values for ARDS and COPD. As there are fewer cases of ARDS and COPD, these values are very hard to find, and as a result, it is made much more difficult to study them. There is rarely a steady-state, and the definition of ARDS, for example, is constantly being reviewed and revised.

It is only in recent years that certain authors have begun to publish data for trainers to use in simulation-based training [2]. There are an array of subtle details that are still not known, for instance, pV curve details such as inflection points. Because of this, it is the responsibility of the trainer to match the parameters with the real cases.

Discussion

Parameters set in simulation are used to offer insight, and the results of simulation should typically be obvious to the learner. Subtle changes may go unnoticed, but marked differences will help to achieve the learning goal. The values provided in Table 1 were selected from available literature to try and produce noticeable differences for simulation-based teaching.

These values are not intended to represent normal values for actual patients. This is because the scientific epidemiologic basis is lacking, and the parameter values have to be considered anecdotal. However, the values of Table 1 were measured on actual patients and are real as a result. Trainers may find it necessary to make even larger differences between normal, ARDS, and COPD cases than are presented in Table 1. For example, in order to show the effect of increased Raw in COPD, it may be necessary to increase resistance up to 50 mbar/(L/s) on the simulator.

It is important to remember that tubing, connectors, and filters will all have a real impact on airway resistance. In Table 1, the influence of a 7 mm endotracheal tube is included in the Raw value (on average, a 7 mm tube was used by the investigators). Other components such as heat-and-moisture exchangers are not included and, if added to the circuit during a patient case simulation, these components will automatically increase resistance because of their physical presence.

Airways resistance is often flow dependent, and as such it is important to state the flow at which the resistance measurements were made. Unfortunately, this information was not available in the cited papers.

There exists significant levels of confusion around the definition of compliance, but this article is not intended to clear up this area of contention. All compliance values stated in Table 1 are quasi-static compliances, meaning they are measured in no-flow conditions or calculated to represent no-flow conditions.

Dead space in Table 1 is airways dead space, meaning the series component of dead space. Tidal volume needs to be larger than airways dead space to create any alveolar ventilation. Additionally, alveolar dead space or physiological dead space is not considered as part of this article.

Conclusion

To transition from conventional simulation to autonomous simulation requires a considerable effort. Parameter values that are pertinent for any given case must be selected before simulation can begin, but the return on this investment is substantial, resulting in highly consistent simulation experiences and a significantly reduced cost of operation.

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Acknowledgments

TestChest is a registered trademark of Organis GmbH, Landquart,

Switzerland.

About neosim AG

neosim is a Swiss company founded by experts with strong background in lung physiology and mechanical ventilation of intensive care patients. The mission of neosim is to bring high-fidelity physiology and pathophysiology to the patient simulator community.

For training and education of clinicians, especially respiratory therapists and intensive care professionals, neosim simulators create realistic breathing in health and disease. In contrast to other simulators, neosim's simulators can be treated with intensive care therapy methods and responds like a real human patient. The result manifests itself clinically and can be measured quantitatively with state-of-the-art monitoring in real-time.

Last updated: Jun 17, 2020 at 10:31 AM

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