neosim

LuSi Case Development

presented by the neosim academy

neosim academy

c/o neosim AG
Susenbühlstrasse 12
CH-7000 Chur
Switzerland
www.neosim.ch

Written by Josef X. Brunner, PhD, Chur, c/o neosim AG, Susenbühlstrasse 12, CH-7000 Chur, Switzerland

ISBN 978-3-9524884-2-3
Year of publication: 2020, Rev. 1.0
Printed in Switzerland

Contents

Purpose and definitions 6
Purpose 6
Definitions 6
Fundamental modes of operation 7
Parameter definitions 8
Variables/outcomes 12
Normal or predicted values 13
Tutorial 1 : Passive ventilation 14
Base Case : Normal lung mechanics 14
Progression 1: Decreased lung compliance, stiff lungs 14
Progression 2:Increased airways resistance, obstructive airways 14
Tutorial 2: Spontaneous breathing 15
Base Case: normal breathing 15
Progression 1: Creating tachypnea by limiting inspiratory force 16
Progression 2: Creating tachypnea by increasing metabolic demand 16
Progression 3: Creating tachypnea by adding alveolar dead space 17
Progression 4: Creating tachypnea by fatigue due to increased work of breathing (WOB) 17
Tutorial 3: Creating hypoxemia 18
Base Case: Hypoxemia caused by hypoventilation 18
Progression 1: Hypoxemia caused by diffusion limitation 18
Progression 3: Hypoxemia caused by lung collapse, responder to recruitment 19
Progression 4: Hypoxemia caused by lung collapse, non-responder to recruitment 20
Tutorial 4: Creating complex cases 21
Base Case: Respiratory Distress Syndrome 21

Progression 1: RDS with Apnea and drops in saturation 22
Sample cases (may vary with shipment) 23
Respiratory distress syndrome RDS 23
Transient Tachypnea of the Newborn TTN 24
Chronic lung disease BPD 24
Chronic lung disease CLD 25
Meconium aspiration syndrome MAS 25
Persistent pulmonary hpyertension PPHN 26
Respiratory mechanics in passive patient 26
Spontaneous respiratory activity 27
Appendix 28
Flow chart to create respiratory distress (tachypnea) 28
Flow chart to create hypoxaemia 28
References 29

Disclaimer

neosim does not warrant that the LuSi will work properly in all environments and applications, and makes no warranty and representation, either implied or expressed, with respect to the quality, performance, merchantability, or fitness for a particular purpose.

neosim has made every effort to ensure that this Manual is accurate; neosim disclaims liability for any inaccuracies or omissions that may have occurred. Information in this Manual is subject to change without notice and does not represent a commitment on the part of neosim. neosim assumes no responsibility for any inaccuracies that may be contained in this Manual. neosim makes no commitment to update or keep current the information in this Manual, and reserves the right to make improvements to this Manual and/or to the products described in this Manual, at any time without notice. If you find information in this manual that is incorrect, misleading, or incomplete, we would appreciate your comments and suggestion.

In no event shall neosim be liable for any special, direct, indirect, consequential, or incidental damages or any damages whatsoever, whether in an action of contract, negligence or other tort, arising out of or in connection with the use of LuSi or the contents of the Manual.

This Manual offers medical and physiological information and is designed for educational purposes only. You should not rely on this information as a substitute for, nor does it replace, professional medical advice, diagnosis, or treatment.

Purpose and definitions

Purpose

The purpose of this manual is to help LuSi users create clinical cases for simulation based training.

LuSi^{LIFE} is shipped with the tutorials described in this booklet. Those scenarios are labelled with the following icon:

This manual is not intended to be a text book for neonatal physiology and pathophysiology.

Definitions

The definitions used herein are taken from the literature. To avoid ambiguities, the parameters are defined in the tables below.

For all other definitions, please consult the “Physiological models” document from neosim AG.

IMPORTANT NOTICE

LuSi is an interactive educational system developed to assist a certified instructor. It is not a substitute for a comprehensive understanding of the subject matter and not intended for clinical decision making.

Fundamental modes of operation

LuSi offers different degrees of autonomous operation. In the first revision of LuSiLIFE, the selection is made by virtue of two Parameters. In the present revision, control was simplified, gas exchange is now always autonomous and the respiratory control is either governed by the user or by the built-in control algorithm. The selection of one or the other is by virtue of setting the “Central respiratory control” parameter, as explained in the following Figure.

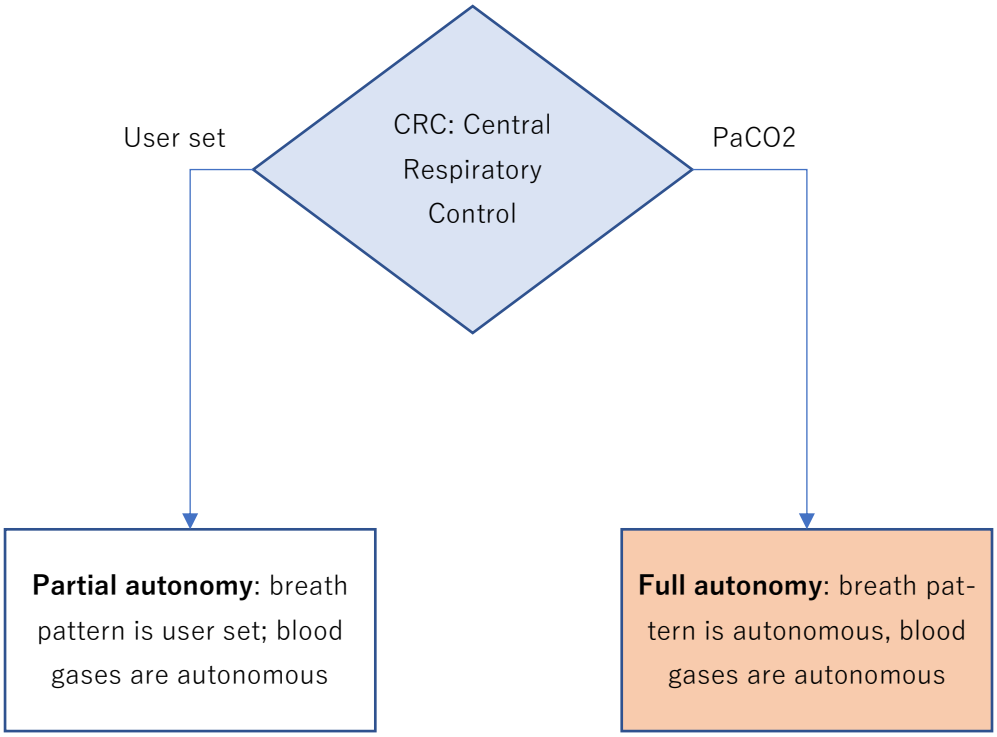


Figure 1: Fundamental operation of LuSi. If “user set”, the breath patteren including Pinps and Respiratory Rate are determined by the trainer. If “PaCO2” control is used, Pinsp and Respiratory Rate are controlled by LuSi to achieve the trainer set PaCO2 and the settings of Pinsp and Respiratory Rate are the maximum values achievable by the controller. Color code is repeated in tables 3 and 5.

For fully autonomous operation “Central respiratory control” is set to “PaCO2”. If you want to prescribe the breath pattern, you select “User set”. You can obtain a completely monotonous breath pattern by setting the Pinsp and RR variation to 0 (see tables below).

Parameter definitions

The Parameters given in the tables below define physiology and pathophysiology and are either set by the trainer or autonomously adapted. Grey shaded entries are system set.

Table 1: Lung mechanics	Effects	Autonomy
Total resistance, Rtot (mbar/(L/s))	Creates flow dependent pressure drop	Trainer set
Expected FRC (ml)	Is reference for complete recruitment	Trainer set
P/V curve (24 combinations)	Creates volume dependent pressure drop	Initial value is trainer set, may be influenced by recruitment and collapse
Degree of lung collapse (%)	Creates Qs/Qt	Initial value is trainer set, may be influenced by recruitment and collapse
Recruitability (ml/mbar)	Creates lung recruitment	Trainer set
Recruitability threshold (mbar)	Defines at what pressure recruitment starts	Trainer set
Recruitment time constant (sec)	Defines how fast recruitment is	Trainer set
Lung collapse threshold (mbar)	Defines at what pressure lung collapses	Trainer set
Lung collapse time constant (sec)	Defines how fast collapse is	Trainer set
Chest wall compliance (ml/mbar)	Influences pleural pressure	Trainer set
Total respiratory compliance Crs (ml/mbar)	Initial value determined by P/V curve selection, may change during simulation due to recruitment or collapse	Initial value is trainer set, may be influenced by recruitment and collapse
Lower inflection point LIP (ml)	Initial value determined by P/V curve selection, may change during simulation due to recruitment or collapse	Initial value is trainer set, may be influenced by recruitment and collapse
Compliance below LIP (ml/mbar)	See chapter on P/V curve	Hardware constant
Upper inflection point UIP (ml)	See chapter on P/V curve	Hardware constant
Compliance above UIP (ml/mbar)	See chapter on P/V curve	Hardware constant

Table 2: Haemodynamics	Effects	Autonomy
Total blood volume (ml)	Affects response time of blood gases	Trainer set
Cardiac Output (ml/min)	Affects response time of blood gases	Trainer set
Pulse rate (/min)	None, for immersive effect only	Partial, drops if ventilation is < 1L/min
Pulse variability (%)	Affects pulse rate	Random
Central bradycardia with apnea (/min)	Specifies pulse rate drop during apnea	Only active if apnea is set
BP sys (mmHg)	None, for immersive effect only	Trainer set
BP dia (mmHg)	None, for immersive effect only	Trainer set
BP mean (mmHg)	None, for immersive effect only	Trainer set
Plethysmogram Variation (%/mbarPpl)	Affects plethysmogram amplitude	Effect depends on airway pressures (learner set) and chest wall compliance (trainer set)
Right Left Shunt via PDA	Adds a “true” shunt fraction.	Trainer set

Table 3: Respiratory control	Effects	Autonomy
Central Respiratory Control (CRC)	User set: breath pattern constant PaCO2: breath pattern is automatic	Full Autonomy if set to PaCO2
PaCO2 respiratory centre target (mmHg)	Target value of respiratory centre. Only active if CRC is set to PaCO2.	Trainer set
Pinsp (mbar)	Inspiratory muscle pressure Pinsp if CRC is "User set"	Trainer set
	Maximal inspiratory muscle pressure Pinsp if CRC is "PaCO2"	Maximum value, trainer set
Inspiratory curve form	Select "Sinus" for quiet breathing, "Exponential" or "Square" for pressure supported breathing or when in distress	Partial, depends on respiratory support device
Variation of Pinsp (mbar)	Adds variability to breath pattern	Random
Expiratory wave form	Select "Sinus" for quiet breathing, "Exponential" or "Square" for pressure supported breathing or when in distress	Trainer set "Grunting" creates some noise, can also be used to simulate mucus in bronchi
Expiratory muscle tone (% Pinsp)	May create lung recruitment**; also reduces the available pressure to create tidal volume and may effect V'A	Trainer set
RR (/min)	Actual respiratory rate if CRC is "User set"	Trainer set
	Maximal respiratory rate if CRC is "PaCO2"	Maximum value, trainer set
Variation of Resp.Rate (%)	Adds variability to breath pattern	Random. Set with caution when CRC is active! 10% is usually enough.
Sigh rate (/hour at 2* Pinsp)	Sigh will be at 2 times the actual Pinsp value	Trainer set
Apnea rate (/h)	Intervals of apnea May create lung collapse**	Trainer set. NOTE: Prerequisite for bradycardia to show-up (see Table on Haemodynamics)
Variation Apnea Rate (%)	Adds variability to breath pattern	Random
Apnea time (sec)	No breath for the specified time	Trainer set

*** Recruitment effect depends on Recruitability settings (see Table 1); collapse effect in Apnea depends on derecruitment settings (see Table 1)*

Table 4: Gas exchange	Effects	Autonomy
CO2 production (ml/min STPD)	Determines ventilatory need	Trainer set
Airways dead space (ml)	Determines alveolar ventilation in conventional ventilation/breathing	RR<300 bpm: trainer set RR>300 bpm: Vd not used
DCO2 for HFV factor	Determines alveolar ventilation in HFV: $V'A=k*f*V_t^2$	RR<300 bpm: DCO2 not used RR>300 bpm: trainer set
Alveolar dead space ventilation (%)	Creates difference between end-tidal and arterial PCO2	RR<300 bpm: trainer set RR>300 bpm: not used
O2 diss.curve shift DP50 (Torr)	Shifts the oxygen dissociation curve	Trainer set
Fetal Hb (%)	Elevates SpO2 at reduced FiO2	Trainer set
Diffusion limitation (mmHg)	Creates response to increased FiO2	Trainer set
Base Excess (mEq/L)	Creates metabolic effects	Trainer set
Temperature (Degrees C)	No effect, for immersive experience only	Trainer set

Table 5: Special effects	Effects	Autonomy
Leak (on, off)	Creates leak	Trainer set
Added dead space (ml)	Decreases alveolar ventilation	Trainer set
PtcCO2 Bias (mmHg)	Creates error in PtcCO2	Trainer set
Capnometer T90	Creates fast or slow response	Trainer set
Movement artefacts	Creates noisy pulse oximeter plethysmograms	Yes

Variables/outcomes

The following variables change as a result of respiratory treatment provided to LuSi by the learner for example CPAP, oxygen supply or mechanical ventilation.

Table 6: Variable/outcome	
TLV in ml	Total Lung Volume Vlee
FO2	Measured in the alveoli
PaO2	Arterial
SvO2	Mixed venous
SpO2 pre-ductal	See physiological model
SpO2 arterial	See physiological model
etCO2	Exhaled PCO2
Vt	Tidal volume
RR	Is the overal respiratory rate
Pmax in mbar	Depends on muscle activity and respiratory support
Pdrive in mbar	Inspiratory muscle effort
Pmin in mbar	Depends on muscle activity and respiratory support
V'A	Depends on RR, Vt, etc.
PaCO2	Depends on alveolar ventilation
pH	Depends on PaCO2 and BE
CollapsedLung	Depends on recruitment
Pulse rate	Drops if apnea persists
QsQt	Trainer set, constant for a given progression
Temperature	Trainer set, constant for a given progression
Bpsys	Trainer set, constant for a given progression
Bpdia	Trainer set, constant for a given progression
Bpmean	Trainer set, constant for a given progression
RR spont in /min	Depends on setting of Central Respiratory Control
Patient Pitch	Depends on position and movement of LuSi
Patient Roll	Depends on position and movement of LuSi

Normal or predicted values

Disease is often defined as deviation from normal values or predicted values. The method to create different scenarios is to change the predicted values to pathological values. The prediction of parameters for normal lungs depends mainly on patient weight and gestational age. Because weight and g.a. are closely correlated in normal babies, weight is the dominant factor.

NOTE: Normal or predicted values are hard to find – although many papers are anecdotal, they provide valuable starting values. The data provided by these papers is assembled in Table 7 and provides the default parameters loaded when starting a new simulation. The data corresponds to a baby girl born at 36 weeks, 2500g, 51cm length and 0.17m^2 body surface area.

Table 7: Normal values	**Predicted normals**	**SI units**	**LuSi settings**	**Reference**
FRC	58	ml	58	1
Compliance	2	ml/mbar	P/V curve 0	12
Resistance	48	mbar/(L/s)	40..60	4, Fig. 4.8
Cw	7	ml/mbar	7	7
V'CO2	16	ml/minSTPD	16	Brody
TBV	196	ml	200	5,8,11
C.O.	603	ml/min	600	9
Pulse	146	bpm	146	10
Pulse variability	5%	bpm	105	10
SBP	72 (58 in the NICU)	mmHg	58	3
DBP	50 (36 in the NICU)	mmHg	36	3
MBP	59 (46 in the NICU)	mmHg	46	3
Apnea	10	per hour	10	6
Apnea duration	20	sec	20	6
Vdaw	5	ml	5	6

Tutorial 1 : Passive ventilation

Base Case : Normal lung mechanics

The most simple application of LuSi is to use her as compliance and resistance model. For this application, muscle activity needs to be set to zero. Leave all parameters at default, except:

- Set Central respiratory control to user set
- Set Pinsp to 0mbar

LuSi can be ventilated in any controlled mode, including ventilation bag. Compliance and resistance values are as set in Table 7.

Progression 1: Decreased lung compliance, stiff lungs

Leave all parameters at default, except:

- Set Central respiratory control to user set
- Set Pinsp to 0mbar
- Set P/V curve to #24

LuSi can be ventilated in any controlled mode, including ventilation bag. However, because of the stiff lung, the pressures needed to achieve a certain volume will be much higher now. The respiratory time constant will be much shorter and expiratory flows will demonstrate a high peak flow with rapid descent.

Progression 2:Increased airways resistance, obstructive airways

Leave all parameters at default, except:

- Set Central respiratory control to user set
- Set Pinsp to 0mbar
- Set Total airways resistance to 250..350 mbar/(L/s)

LuSi can be ventilated in any controlled mode, including ventilation bag. However, because of the high airways resistance, the pressures needed to achieve a certain volume will be much higher. The respiratory time constant will be much longer and expiratory flows will be very slow. Achieving adequate alveolar ventilation might require to increase respiratory rate and this will create breath-stacking and overinflation of the lungs.

Tutorial 2: Spontaneous breathing

Base Case: normal breathing

A normal breath pattern results if the predicted values (see table above) are entered. This is the default case. Since “Central respiratory control” is set to “PaCO2”, LuSi will work in “Full autonomy” (see Figure 1).

Note the following settings:

- Respiratory Control Centre: PaCO2
- PaCO2: 40mmHg, is the target value for the central respiratory control (see also document on Physiological models by neosim).
- Pinsp: 20 mbar – will give the controller freedom to move up to 20 mbar – however, because the lungs are normal, inspiratory pressures of much less than 20mbar will result
- Variation of Pinsp: 1 ml – will create variations in tidal volume
- RR: 80 bpm – will give the controller freedom to move transiently up to 80 bpm – however, because the tidal volume will be achieved and CO2 production is normal, a normal rate of around 35 bpm will result
- Variation of Resp. Rate: 10% - will create variations in inspiratory and expiratory time
- Inspiratory curve form: sinus – will create quiet breathing
- Expiratory curve form: sinus – will create quiet breathing

As a result, LuSi will maintain normal blood gases with room air at normal respiratory rates and normal tidal volumes of around 15ml (3 times the entered Vdaw) plus/minus the variability entered.

Progression 1: Creating tachypnea by limiting inspiratory force

Tachypnea results when respiratory rate is increased to compensate for inadequate alveolar ventilation. Tachypnea can be created as a static response by setting high respiratory rate and small tidal volume. Alternatively, tachypnea results when Central Respiratory Control is active but the capacity of the patient is limited on purpose, as explained in the following.

Leave all parameters in normal and only change the following:

- Set Pinsp to 8mbar

Reducing the maximal inspiratory pressure Pinsp (Respiratory Control table) to 8 mbar, for example, will limit tidal volume creation and thus alveolar ventilation per breath. LuSi will increase respiratory rate to compensate and may become tachypneic.

LuSi will respond to pressure support because tidal volume will be increased by pressure support. Such volume increase leads to higher alveolar ventilation and LuSi will drop the respiratory rate if the PaCO2 target can be reached.

Progression 2: Creating tachypnea by increasing metabolic demand

Leave all parameters in normal and only change the following:

- Set CO2 production to 20 ml/min

Increasing CO2 production (Gas Exchange table) from 16 to 20 will increase the need for ventilation and thus the respiratory rate.

LuSi will not respond much to respiratory support because the need for higher ventilation is dictated by the increased metabolic demand.

Progression 3: Creating tachypnea by adding alveolar dead space

Leave all parameters in normal and only change the following:

- Set Alveolar dead space ventilation to 40%

Adding alveolar dead space ventilation (Gas Exchange table) makes alveolar ventilation less effective (for example with pulmonary embolism) and increases the need for ventilation. LuSi will increase respiratory rate to compensate for alveolar dead space which will eventually lead to tachypnea.

LuSi will not respond to respiratory therapy.

Progression 4: Creating tachypnea by fatigue due to increased work of breathing (WOB)

Leave all parameters in normal and only change the following:

- Set P/V curve to #24
- Set Total resistance to 60..100 mbar/(L/s)
- Set Pinsp to 10mbar

WOB is increased when compliance decreases and airways resistance increases. Compliance decrease comes with P/V curve #24 (smallest compliance, presence of a lower inflection point). Airways resistance can be increased to further increase WOB.

Exacerbation results, when Pinsp is reduced, for example < 10bar. When CRC is active, Pinsp is the maximum value available for the Respiratory Control Centre and LuSi will not be able to achieve the target tidal volume of 3*Vd. To maintain the target PaCO2, LuSi will compensate with increased respiratory rate.

To make the simulation experience even more realistic, periods of apnea can be added (Apnea period and Duration of Apnea in Respiratory Control table).

LuSi will respond to pressure support ventilation

Tutorial 3: Creating hypoxemia

Hypoxemia can be caused by hypoventilation when breathing room air. In such cases, hypoxemia can easily be corrected by providing oxygen to the patient. Hypoxemia can also be caused by lung collapse and/or by diffusion limitation.

Base Case: Hypoxemia caused by hypoventilation

Leave all parameters in normal and only change the following:

- Set Pinsp to 10mbar
- Set Respiratory Rate to 20 /min

Hypoventilation can be created manually: Set the Pinsp to 10mbar (Respiratory Control table) and Respiratory Rate to 20 bpm. These two settings will limit the Respiratory Control Centre and create hypoventilation, thus hypercapnia and therefore hypoxemia when breathing room air.

- LuSi will respond to increased FiO2
- pressure support ventilation because this increases Vt
- time cycled pressure controlled ventilation because it may increase Vt and respiratory rate.

Progression 1: Hypoxemia caused by diffusion limitation

Leave all parameters in normal and only change the following:

- Set Pdiff to 300

In certain diseases, alveolar gas will not equilibrate with end-capillary blood. In LuSi, this is achieved by setting Pdiff to values of 200 and above (Gas Exchange table). Hypoxemia will result even in normocapnia and normoventilation or even hyperventilation.

LuSi will respond to increased FiO2.

Progression 3: Hypoxemia caused by lung collapse, responder to recruitment

Leave all parameters in normal and only change the following:

- Set P/V curve to #24
- Set Lung Collapse to 40%
- Set Recruitability to 3ml/mbar
- Set Recruitment Time constant to 8 seconds
- Set Recruitability threshold to 10mbar
- Set Lung collapse threshold to 3mbar
- Set Collapse time constant to 1 second

Select P/V curve #24 and set Degree of Lung Collapse to 40% (Lung Mechanics table). Enable recruitment (set Recruitability to a value of 2-5 and Recruitment Time Constant to 5-10 seconds in Lung Mechanics table) above a certain level of pressure, for example 10mbar (set Recruitability threshold to 10mbar in Lung Mechanics table). Enable lung collapse when pressures fall below 3mbar (set Collapse threshold to 3mbar and Collapse time constant to 1 second in Lung Mechanics table).

LuSi will try to maintain normal ventilation thus normocapnia. However, because of lung collapse, there will be significant venous admixture and arterial saturation will be reduced.

LuSi will respond to increased airway pressures – i.e. recruitment manoeuvres. As long as pressure is above 10mbar, lung is recruited. If pressure falls below 3mbar, lung collapses rapidly. LuSi will not respond to increased FiO2.

Progression 4: Hypoxemia caused by lung collapse, non-responder to recruitment

Leave all parameters in normal and only change the following:

- Set P/V curve to #24
- Set Lung Collapse to 40%
- Set Recruitability to 0ml/mbar
- Set Recruitment Time constant to 8 seconds
- Set Recruitability threshold to 50mbar
- Set Lung collapse threshold to 3mbar
- Set Collapse time constant to 1 second

Select P/V curve #24 and set Degree of Lung Collapse to 40% (Lung Mechanics table). Disable recruitment, essentially by setting Recruitability to 0 ml/mbar.

LuSi will try to maintain normal ventilation thus normocapnia. However, because of lung collapse, there will be significant venous admixture and arterial saturation will be reduced.

LuSi will NOT respond to increased airway pressures – i.e. recruitment manoeuvres. LuSi will not respond to increased FiO2.

Tutorial 4: Creating complex cases

The two pathological developments described above can be combined to create a more complex simulation experience.

Combine any of the above described scenarios of tachypnea with hypoxemia. In the following, two complex combinations are illustrated.

Base Case: Respiratory Distress Syndrome

WOB is increased when compliance decreases and airways resistance increases. Compliance decrease results when the P/V curve #24 is selected (smallest compliance, presence of a lower inflection point).

Reduction of lung compliance is due to lung collapse and lung volume needs to be reduced also (Degree of Lung Collapse in Lung Mechanics table).

Exacerbation results, when Pinsp is reduced to <10mbar, i.e. when the respiratory muscles are too weak to compensate for the reduced compliance.

Because the lungs are made to collapse, hypoxemia will result in combination with tachypnea.

LuSi will respond to pressure support with improved CO2 removal. LuSi will respond to recruitment manoeuvres, if recruitment is made possible as described in the Hypoxemia case before. If not, LuSi will not respond to recruitment manoeuvres.

Progression 1: RDS with Apnea and drops in saturation

The scenario described above will lead to hypoxemia. However, sometimes babies are able to recruit lung spontaneously and hypoxemia will be less pronounced. If these babies stop breathing to get some rest (or for whatever other reason), the lungs may collapse and transient, partly reversable hypoxemia will result.

For Lung Mechanics, set the following parameters (leave the rest in default):

- Total resistance to 40..60.
- P/V curve to #24
- Degree of Lung Collapse to 40%
- Set Recruitability to 4ml/mbar, Recruitability threshold to 1mbar and Recruitment time constant to 5 seconds.
- Set Lung collapse threshold to 2mbar and Lung collapse time constant to 2 seconds.

For Respiratory Control parameters set the following (leave the rest in default):

- Pinsp to 10mbar, variation to 1mbar
- Expiratory muscle tone to 20%
- RR to 90 /min, variation to 6%
- Apnea rate to 30/h, Variation Apnea Rate to 30%
- Apnea time to 20 sec and Variation of Apnea Time to 40%

For the Gas Exchange parameters set the following:

- CO2 production to 18 ml/min (slightly increased due to high WOB)
- Airways dead space to 4ml (slightly reduced due to reduced end-inspiratory lung volume)
- Alveolar dead space ventilation to 20%
- Diffusion limitation to 200 mmHg (will create moderate response to FiO2)

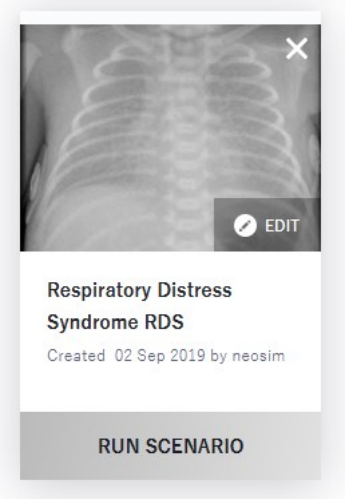
Apnea will consistently lead to drop in saturation. The added variability will create a "chaotic" breathing pattern.

LuSi will respond to FiO2, small levels of CPAP and pressure support.

Sample cases (may vary with shipment)

All sample cases are provided with pre-sets. To view those pre-sets, export each case to PDF, available in the EDIT window of each scenario. All X-rays are reproduced by permission of the editor [13].

Respiratory distress syndrome RDS



RDS “consist of tachypnoea (respiratory rate >60 breaths · min–1), tachycardia (heart rate >160 beats · min–1), nasal flaring, grunting, chest wall recessions (suprasternal, intercostal and subcostal), cyanosis and apnoea.” (Gallacher et.al.). LuSi cannot simulate all of the clinical signs and symptoms, for example nasal flaring, grunting and chest wall recessions. Therefore, LuSi will provide a limited representation of RDS.

Setting the parameters as suggested below and quantified in the LuSiLIFE cases, tachypnea and hypoxemia and hypercapnia can be produced. Because expiratory muscle tone is increased and the lungs are made recruitable, venous admixture is at a controlled level. During apnea the lungs will de-recruite and venous admixture will increase leading to sever hypoxemia.

The X-ray corresponds to Fig.1 Donoghue et.al.

Transient Tachypnea of the Newborn TTN

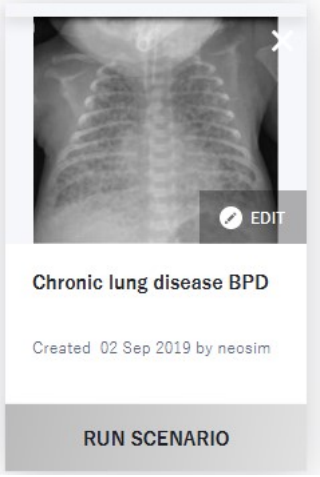
"Transient tachypnoea of the newborn (TTN) is the most commonly diagnosed respiratory condition in term newborn infants." (Gallacher et.al.)

Tachypnea can be simulated by LuSi in a number of ways. The most simple approach is to increase the respiratory rate. However, doing this will create a monotonous increase of respiratory rate, non-responsive to treatment.

The suggested implementation simulates tachypnea by reducing the inspiratory force of the baby thus forcing an increased respiratory rate to achieve normocapnia.

The X-ray corresponds to Fig.8 Donoghue et.al.

Chronic lung disease BPD



“CLD is defined as supplemental oxygen dependency for at least 28 days from birth, and at 36 weeks corrected gestational age. ⋯ The presence of chorioamnionitis, mechanical ventilation ⋯, postnatal sepsis ⋯, oxygen toxicity ⋯ and fluid overload often due to the presence of a patent ductus arteriosus ⋯ are all risk factors for CLD. The common pathway for each of these mechanisms is thought to be the generation of an inflammatory response within the lungs of preterm infants” (Gallacher et.al.)

The X-ray corresponds to Fig.7 Donoghue et.al.

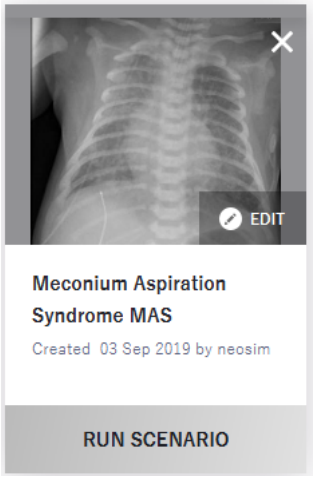
Chronic lung disease CLD

See same description as BPD. In this case, a first Progression is included to simulate muscle paralysis in order to enable High Frequency Ventilation.

NOTE: The recruiting effects of mean airway pressure are determined by the recruitment threshold.

In progression 1, respiratory activity is User set and Pinsp is set to 0. These settings effectively create muscle paralysis.

Meconium aspiration syndrome MAS



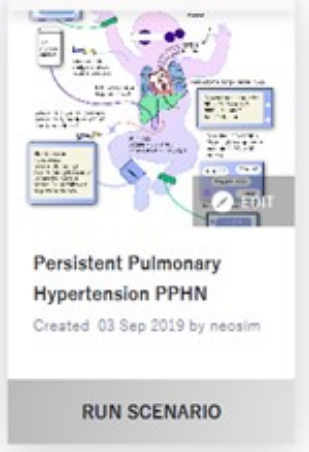
"The inhaled meconium adversely affects the lung in several ways:

- Mechanical obstruction of the airways leading to ventilation/perfusion mismatch
- Chemical pneumonitis
- Infection

The resulting inflammatory reaction causes swelling which may block small airways; cause surfactant dysfunction; impair gaseous exchange and result in PPHN." (Gallacher et.al.)

The X-ray corresponds to Fig.9 Donoghue et.al.

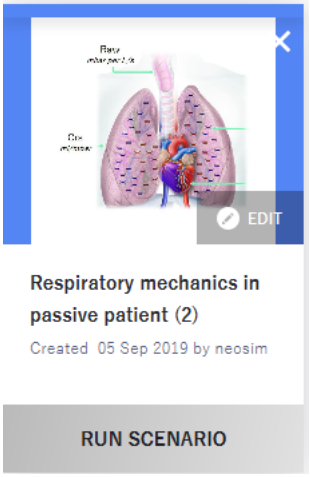
Persistent pulmonary hpyertension PPHN



“Following birth, the combination of oxygen and respiratory movements facilitate a drop in the PVR ⋯. Failure of this transition results in persisting high PVR resulting in right to left shunting at the level of the PDA and foramen ovale, leading to pulmonary hypo-perfusion, hypoxia and acidosis ⋯. ⋯ PPHN is difficult to differentiate from cyanotic congenital heart disease as presentation is often very similar.” (Gallacher et.al.)

Figure illustrates potential pathways to treat PPHN

Respiratory mechanics in passive patient

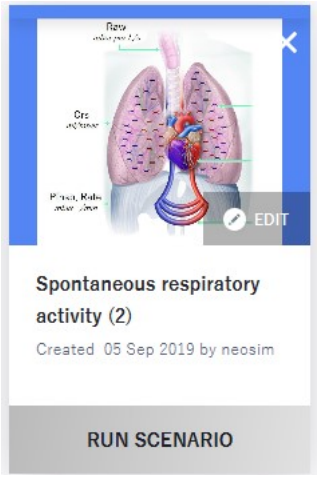


Respiratory system compliance can be changed by changing the P/V curve: from maximal compliance (P/V curve #0) to a minimal compliance (P/V curve #24). Upper inflection point remains at around 25mbar, a lower inflection point at around 3mbar is created by P/V curve #24.

Total respiratory resistance can be adjusted in 6 steps.

NOTE: Central respiratory control (CRC) is set to User set and Pinsp and Variation of Pinsp are set to 0 to make a passive patient.

Spontaneous respiratory activity



Spontaneous activity is either controlled by PaCO2 or by the user. Control is by virtue of the parameter “Central respiratory control”. When set by the user (“User set”), the parameters Pinsp and RR control the breath pattern.

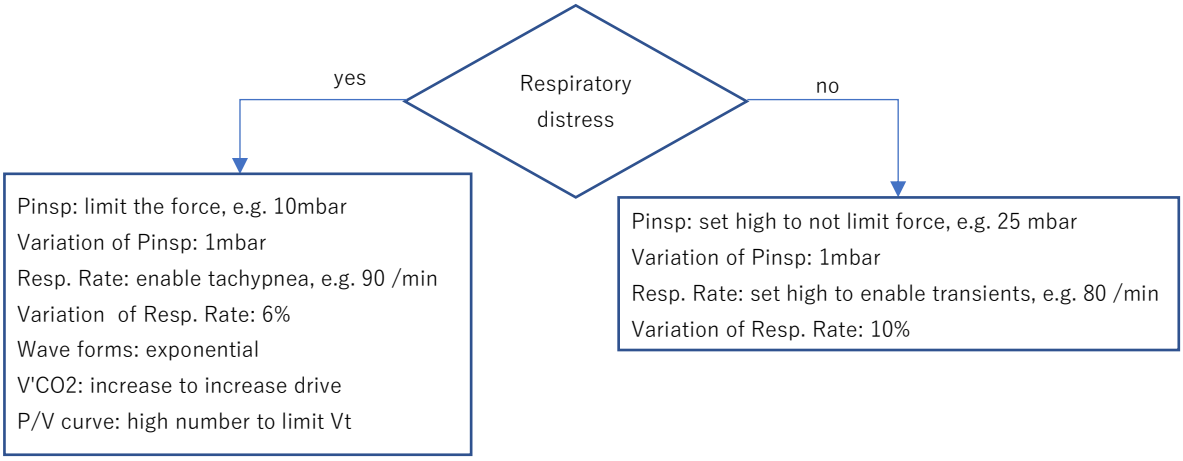
In Base Case, a normal breath pattern will result.

In Progression 1, inspiratory pressure is reduced, resulting in a reduce tidal volume and increased PaCO2.

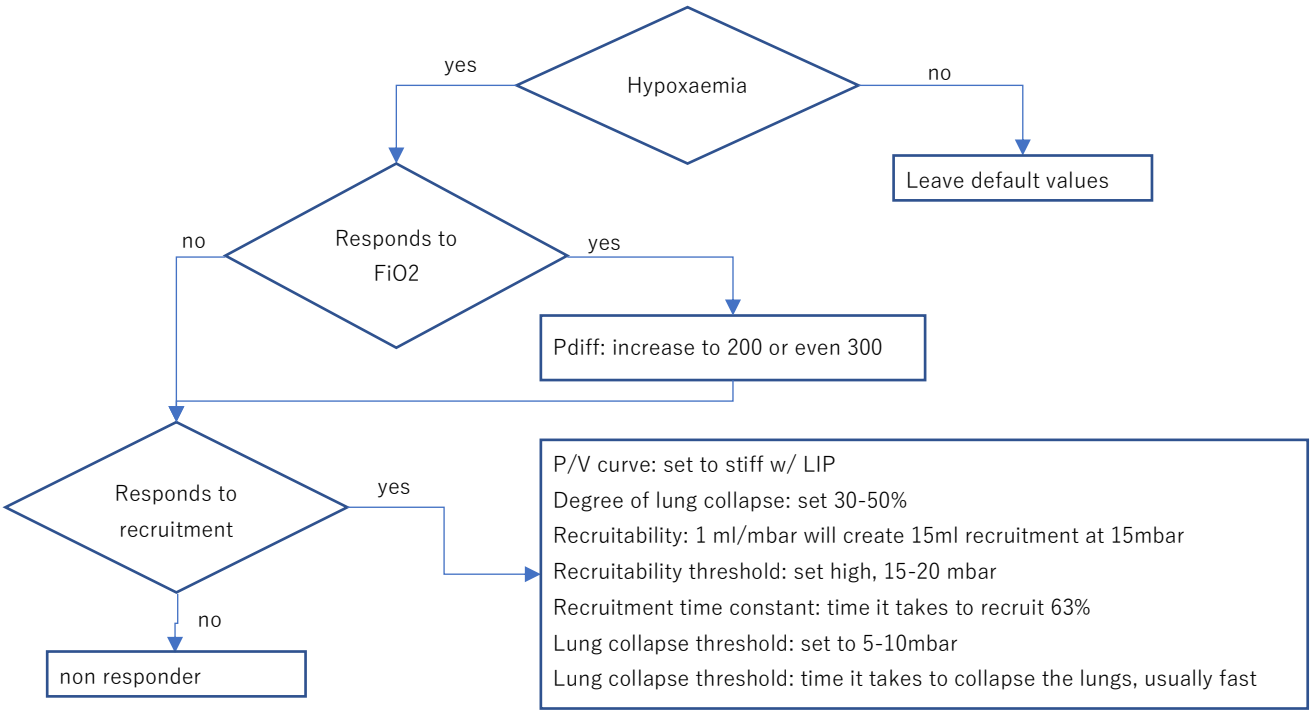
In Progression 2, inspiratory pressure is slightly reduced and respiratory rate increased with markedly increased resistance. This will lead to incomplete inhalation and exhalation due to the increased time-constant.

Appendix

Flow chart to create respiratory distress (tachypnea)



Flow chart to create hypoxaemia



References

1 Latzin P, Roth S, Thamrin C, Hutten GJ, Pramana I, Kuehni CE, Casaulta C, Nelle M, Riedel T, Frey U. Lung volume, breathing pattern and ventilation inhomogeneity in preterm and term infants. PLoS One. 2009;4(2):e4635. doi: 10.1371/journal.pone.0004635. Epub 2009 Feb 27. PubMed PMID: 19247491; PubMed Central PMCID: PMC2645689.

2 Thamrin C, Latzin P, Sauteur L, Riedel T, Hall GL, Frey U. Deadspace estimation from CO2 versus molar mass measurements in infants. Pediatr Pulmonol. 2007 Oct;42(10):920-7. Pub-Med PMID: 17722053.

3 Pejovic B et al: Blood pressure in non-critically ill preterm and full-term neonates. Pediatr Nephrol. 2007:22; 249-257

4 Rimensberger P, editor, Pediatric and Neonatal Mechanical Ventilation, Springer Verlag 2017, ISBN 978-3-642-01218-1, DOI 10.1007/978-3-642-01219-8

5 Russel SJM: Blood volume studies in healthy children. Arch Dis Child 1949 88-98

6 Beck J, Reilly M, Grasselli G, Qui H, Slutsky AS, Dunn MS, Sinderby CA. Characterization of neural breathing pattern in spontaneously breathing preterm infants. Pediatr Res. 2011 Dec;70(6):607-13. doi: 10.1203/PDR.0b013e318232100e. PubMed PMID: 21857389; PubMed Central PMCID: PMC3210880.

7 Papastamelos C, Panitch HB, England SE, Allen JL. Developmental changes in chest wall compliance in infancy and early childhood. J Appl Physiol. 1995 Jan;78(1):179-84.

8 Rawlings JS, Pettett G, Wiswell TE, Clapper J. Estimated blood volume in polycythemic neonates as a function of birth weight. J Pediatr. 1982; 101:594–599.

9 Walther FJ, Siassi B, Ramadan NA, Ananda AK, Wu PY. Pulsed Doppler determinations of cardiac output in neonates: normal standards for clinical use. Pediatrics. 1985 Nov;76(5):829-33.

10 Fabio Augusto Selig, Emanuele Renata Tonolli, Érico Vinicius Campos Moreira da Silva, Moacir Fernandes de Godoy. Heart Rate Variability in Preterm and Term Neonates.Arq Bras Cardiol. 2011

11 Simpson J, Stephenson T:Regulation of extracellular fluid volume in neonates Early Human Development 34(3)1993, 179-190

12 Mortola JP, Fisher JT, Smith B, Fox G, Weeks S: Dynamics of breathing in infants. J Appl Physiol. 1982, 52(2):1209-1215

13 Gallacher DJ, Hart K, Kotecha S: Common respiratory conditions of the newborn. Breathe 2016; 12:30-42

14 Donoghue V. The neonatal chest. Paediatrics Today 2016;12(1):16-29

neosim AG

Susenbühlstrasse 12

CH-7000 Switzerland

www.neosim.ch