Instruction Manual

AVS-1

Advanced Ventilator System

Read instructions carefully before operating this device.

❶ *This device is not to be used for Human Life Support applications.*

❷ *To avoid possible electrical shock, do not operate this device if is wet or has had liquids spilled onto it.*

❸ *Service or calibration procedures should only be performed by qualified personnel familiar with the electrical hazards of line-powered devices.*

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1.0 INTRODUCTION

The AVS-1 Advanced Ventilator System is a versatile, microprocessor-based animal ventilator. It performs volume cycling, pressure cycling, and neural control of ventilation. Additional features include pressure-demand triggering, constant CO_2 ventilation, and facilities for external control of ventilator function. The AVS-1 is capable of ventilating animals ranging from mice to cat-size by plugging in the appropriate external valve assembly.

The AVS-1 is a *flow-time ventilator*. Inspiratory volumes are generated by gating a constant flow into the animal for a given time. This approach permits great flexibility in respiratory timing, since respiratory rate (RR), inspiratory time (TI), and airflow are all independently set. In addition to constant volume ventilation, inspiration may be terminated by a variety of events, including end-inspiratory pressure.

The controls of the AVS-1 are logically arranged into functional groupings. The primary groups are **START INSPIRATION** and **STOP INSPIRATION**. For example, inspiration can be started by a clock, the onset of Phrenic nerve activity, inspiratory effort of the animal (**DEMAND**), or by an external logic signal. Inspiration is terminated by a set of similar functions. These modes can be mixed; *e.g.*, you can initiate inspiration using the **NEURAL** triggering, but terminate with **PRESSURE**. This manual is organized according to such functional control groups.

Figure 1: Model AVS-1 Front Panel

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2.0 VENTILATOR CONNECTIONS AND SETUP

Setting up the AVS-1 is straightforward. The unit may be rack mounted, or can be placed on a benchtop. For basic ventilator functioning, the following connections are required:

❶ Plug the provided power cord into a grounded power outlet. The power supply is universal, so 115V/60Hz or 230V/50Hz mains power is usable.

❷ Place the External Valve Assembly as close to the animal as possible, and plug its cable into the **VALVES** jack located on the rear panel of the AVS-1.

❸ Connect flexible tubing between your air source to the inlet of your flowmeter, from the flowmeter outlet to the valve assembly **FLOW IN** port. Use the included tubing set to connect the valve assembly **CANULA I** and **CANULA E** ports to the "Y" connector (or "W" connector). The distal leg of this fitting attaches to the endotracheal tube of the animal. Connect the pressure monitoring tubing (if used) to the third port on the "W" connector, and plug this into the rear panel **AIRWAY PRESSURE** Luer connector.

❹ For neural triggering or CO_2 control, see separate instructions later in this manual.

❺ For a basic checkout, select **CLOCK** and **TIME** for the **START** and **STOP** functions, respectively. Attach a test balloon in place of the tracheal tube, and if air is flowing through the flowmeter, the balloon should inflate and deflate under the control of the ventilator.

3.0 OPERATING CONTROLS

The operating controls are arranged into functional groups. For most modes of operation, it is only necessary to select an **START INSPIRATION** mode and a **STOP INSPIRATION** mode. The descriptions below pertain to each functional mode of the ventilator.

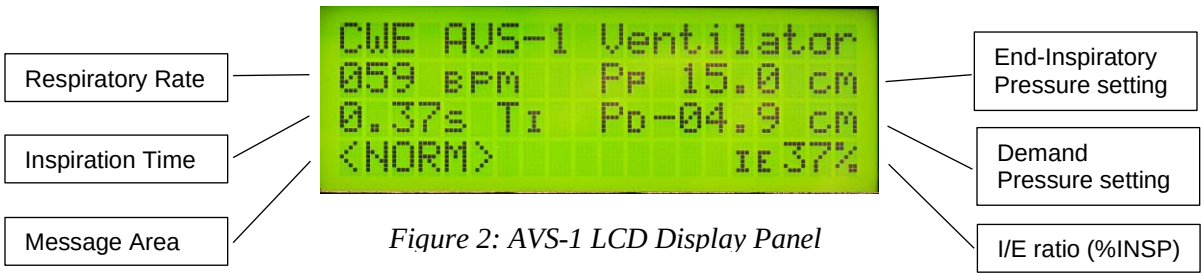

Figure 2: AVS-1 LCD Display Panel

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3.1 VOLUME CYCLED VENTILATION

For volume-cycled ventilation, set **START INSPIRATION** to **CLOCK**, and **STOP INSPIRATION** to **TIME**. This means that a free running clock will start the inspiratory cycle, and an elapsed time will end it. First, set the **INSP TIME** dial to the desired time (range is 0-10 sec). Then adjust the **RESP RATE** knob to set respiratory rate. These settings will be displayed on the LCD display panel.

NOTE: *The range of the **RESP RATE** dial is 10 - 200 breaths/min. Faster or slower rates can be achieved using the external control inputs.*

The final control needed for volume cycled operation is **INSPIRATORY AIRFLOW**. This is set using an external flowmeter. Use the Tidal Volume Tables to determine the appropriate airflow to produce the desired tidal volume. The calculation is simple: VT = Airflow x TI. For example, to set a tidal volume of 10ml with an inspiratory time of 1/2 second, the flow rate should be 20ml/sec, or 1.2 l/min.

3.2 PRESSURE CYCLED VENTILATION

Pressure cycled ventilation uses airway pressure to terminate inspiration. To use this, set **STOP** inspiration to **PRESSURE**. The desired end-inspiratory pressure is set using the **INSP PRESSURE** dial. Note that the range of this control is 0 - 50 cmH_2O, or 5 cmH_2O/turn of the dial. This setting is shown on the LCD display as **PP.**

For the simplest pressure cycled operation, set **START** inspiration to **CLOCK**. This selects the free-running clock, whose rate is set using the **RESP RATE** knob.

Pressure terminated inspiration can also be used with other **START** inspiration modes. For example, **DEMAND** or **NEURAL** can be used to start inspiration. In either case, end-inspiratory pressure will be used to terminate inspiration if **PRESSURE** is selected.

3.3 DEMAND MODE VENTILATION

Demand mode ventilation uses a negative pressure swing to trigger inspiration. An inspiratory effort on the part of the animal causes airway pressure to go negative (below atmospheric pressure). The pressure at which triggering occurs is adjustable via the **DEMAND PRES** dial. When this negative pressure is reached, inspiration begins. Inspiration is terminated by whatever function is selected on the **STOP INSPIRATION** switch (**TIME, PRESSURE**, etc.). The range of the **DEMAND PRES** dial is negative 0 - 10 cmH_2O, or -1.0 cmH_2O per turn of the dial.

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3.4 NEURAL CYCLED VENTILATION

A unique feature of the AVS-1 Ventilator is the ability to synchronize ventilation to Phrenic (or other) nerve activity. Phrenic activity can be used to start and stop, or just to start inspiration. For proper triggering, a Moving Average of the Phrenic activity is required as the input signal. To set up Phrenic cycled ventilation, perform the following steps:

❶ Connect the Moving Average signal to the **MOV AVG IN** jack. Monitor the **MOV AVG MPX OUT** on an oscilloscope. This is a multiplexed signal consisting of the Moving Average, trigger Level 1, and trigger Level 2. A fourth signal is a zero-volt baseline for reference.

❷ Observe that the neural Moving Average rises and falls with nerve activity. Adjust the **LEVEL**1 knob so that the corresponding Level 1 trace is about 1 volt above the zero-volt baseline. Similarly set the Level 2 trace so it is above the Level 1 trace.

❸ Using the **MOV AVG POSITION** knob, position the Moving Average trace so that it is below Level 1 during the expiratory phase (little or no nerve activity). It should be positioned such that it rises up through Level 1 during "neural" inspiration.

❹ Use of Level 2 is optional. It is operational only if **END INSPIRATION** is set to **NEURAL**. Its function is to end inspiration more quickly than if Level 1 is used alone. To use it, adjust the Level 2 trace so that it is slightly below the Moving Average peak. In this way, as soon as the Phrenic starts to fall, inspiration will stop, without waiting for the Moving Average to fall down through Level 1. If you do not want to use Level 1, or you are using the Phrenic only to start inspiration, move Level 2 above the Moving Average range.

❺ After a little experimentation, you will determine how to optimally position the Moving Average trace relative to Level 1. It must be far enough below Level 1 to avoid false triggering from random "bobbles", but close enough to provide quick triggering once the Phrenic turns on.

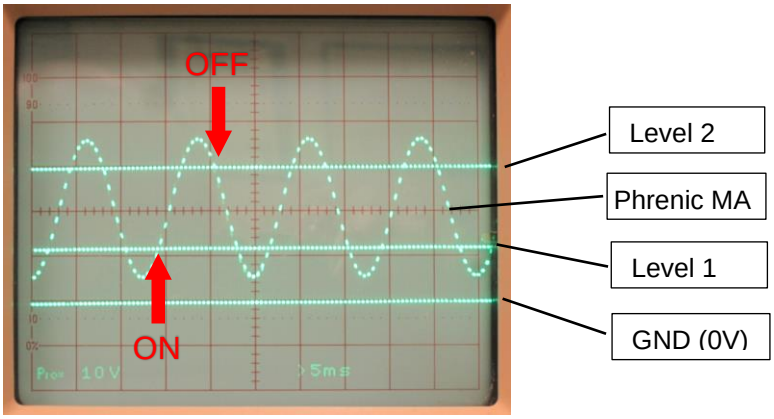

Figure 3: Moving Average Multiplexer (MPX) shown on oscilloscope

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3.41 AUTO MODE

This is a special capability of the AVS-1. When **AUTO MODE** is switched ON, the apnea circuits are monitored to be sure inspiration and expiration are cycling normally. If a long apneic pause (ca. 20 sec) is detected, the controller will automatically revert to normal volume cycled operation, using the current **RESP RATE** and **INSP TIME** settings. The **APNEA** light will blink, and a beeper will sound if this occurs. The LCD display will also indicate the apnea condition.

To restore Phrenic cycled operation, first readjust the Moving Average, if necessary, or fix the nerve electrodes, which may have fallen off or dried out. When all is well, press the **RESET** push-button next to the **APNEA** light. The controller will then return to Phrenic triggering.

NOTE: *It is always good practice to set up the volume mode controls (**CLOCK** and **TIME**) for normal operation before switching to Phrenic cycled ventilation. This will provide for normal ventilation if an apnea is detected and **AUTO** mode is ON.*

3.5 CONSTANT CO_2 VENTILATION

The AVS-1 can be used to maintain a constant end-inspiratory CO_2 level. This function only works in the volume mode of ventilation (**CLOCK** and **TIME**), and operates as follows: The output of a CO_2 analyzer (capnograph) is monitored by the ventilator. The peak end-inspiratory reading is updated each breath. To minimize breath-to-breath variations, a moving average of eight breaths is computed, and updated each breath. This average peak CO_2 is used as the current $ETCO_2$ reading. A target CO_2 value is established (**ACQUIRE** pushbutton), and compared to the current reading. If CO_2 is higher than the target, respiratory rate is increased; if CO_2 is too low, rate is decreased. By changing respiratory rate, but maintaining constant tidal volumes, minute ventilation (MV) is thus decreased or increased, as required.

This simple control technique works well to maintain constant end-tidal CO_2 over time, without the usual knob adjustments necessary on other ventilators. Note that it is not a breath-by-breath servo controller, but rather a smooth, long-term controller. To use the CO_2 mode, set up the AVS-1 as follows:

❶ Connect a CO_2 analyzer in the usual manner to the animal's tracheal cannula. Connect the electrical CO_2 output signal to the **CO_2 IN** jack on the AVS-1. This signal should fall within the range 0 – 5V (scaling is not important). If your signal is ok, jump to step 4 below.

❷ If your CO_2 signal voltage is outside the 5V range, you can adjust its zero offset and scaling. Connect the **CO_2 MONITOR** jack to an oscilloscope input. This is the actual signal used by the controller. Locate the **CO_2 SPAN AND ZERO** trimpots on the front panel of the AVS-1. These are used to adjust the gain and offset of the raw capnograph signal.

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❸ While observing the oscilloscope trace, adjust the CO_2 **SPAN AND ZERO** trimpots so that the peak end-expiratory signal falls within the range 0 - 5V. The actual gain and position is not important; just be sure the peak CO_2 will always fall within 0 - 5V. Be sure to allow for some up and down changes in the peak value as CO_2 changes. This setup procedure will normally have to be performed only once, unless a different capnograph is used.

❹ Before switching CO_2 mode ON, set the ventilator to a basic volume mode by adjusting the **CLOCK** and **TIME** settings as appropriate. Allow the animal to stabilize and adjust the volume mode settings as necessary to achieve the desired $ETCO_2$.

❺ After the animal is stabilized, switch CO_2 mode ON. Allow about one minute for the CO_2 control circuits to read the average $ETCO_2$. Press the **ACQUIRE** pushbutton to signal the controller that this is target value of CO_2 to be maintained. The ventilator will now track this CO_2 level by automatically adjusting respiratory rate, as described above. The LCD display will indicate that CO_2 is being tracked, and whether respiratory rate is being driven up or down to control CO_2.

> ***NOTE:*** *The range of automatic rate adjustment is 10 – 100 bpm. A short beep will occur if the controller reaches either limit. This will be a signal to exit CO2 mode and re-adjust the ventilator for a smaller or larger minute ventilation (MV), as needed. Note that while* <tracking> *is active, you can adjust* ***INSP TIME****, but NOT* ***RESP RATE****.*

❻ While in CO_2 mode, the acquire pushbutton can be pressed at any time to obtain a new target $ETCO_2$. To re-adjust the primary ventilator settings, first exit CO_2 mode. Once stable at the new settings, you can switch back to CO_2 mode and return to CO_2 control as before.

3.6 TRIGGERING FROM EXTERNAL SOURCES

Inspiration can be started and stopped using external logic signals. In this way the ventilator can be controlled by any external logic signal source, such as a computer. As with the other modes of operation, external control can be used for triggering only the start or stop of inspiration, or both. To use external signals, follow the procedure below:

❶ To start inspiration from an external source, select **EXT** on the **START INSPIRATION** switch. To stop inspiration from an external source, select **EXT** on the **STOP INSPIRATION** switch.

❷ The external signals must be TTL compatible (approx. 0 - 5V). A minimum pulse width of about 20mS is required. Both **EXT** inputs are active high; *i.e*. the function is activated when a high logic level is presented. Connect the external signal(s) to the **EXT START** or **EXT STOP** jacks on the front panel. Set the **START**

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INSPIRATION and/or **STOP INSPIRATION** switches to **EXT** to activate the external inputs.

NOTE: *The External Control Inputs are also accessible on the* ***DATA PORT*** *on the rear panel.*

3.7 SPECIAL LCD DISPLAY FUNCTIONS

Besides the basic ventilator parameters and settings described earlier, the LCD display panel provides important information regarding ventilator operation (see Figure 2). The bottom left shows a status message indicating the current mode of operation, as well as the following status messages, described below:

<NORM> This indicates normal inspiration and expiration function.

<APNEA> This shows that an apnea event has occurred.

<TI ERROR> This indicates that the inspiratory **TIME** setting is too long for the current respiratory rate (**CLOCK**). In the example below, the TI overlaps the clock setting, which is invalid. The **IE** measurement will display "==" to indicate this error.

<TRACKING> This indicates that CO_2 is being controlled. In the example below, the up-arrow indicates that the RR is currently being increased.

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3.8 MONITOR OUTPUTS

There are three front-panel outputs which can be used to monitor the operation of the AVS-1 Ventilator. These are the **SYNC OUT**, **ANALOG RATE OUT**, and **PRESSURE OUT**.

SYNC OUT provides a logic signal corresponding to the respiratory phase. During inspiration, **SYNC OUT** is high; during expiration, **SYNC OUT** is low. This output also corresponds to the **INSP** light on the front panel.

ANALOG RATE OUT is a voltage corresponding to the current respiratory rate. The scale of this output is 0 - 200bpm = 0 - 4V out, or 10mV/breath/minute. This output corresponds to the reading on the LCD display, and is updated every 150mS.

PRESSURE OUT is a voltage proportional to airway pressure. Its range is $\pm$5V, with zero volts equal to zero pressure. The scale of this output is 100mV/cmH_2O.

3.9 MANUAL CONTROL OF VENTILATION

The AVS-1 can be operated completely manually, if desired. The **HOLD** switch causes inspiration to be suspended indefinitely. The **MANUAL** push-button causes inspiration to occur for as long as it is held down.

The **HOLD** switch is useful in special situations; *e.g*. to allow CO_2 to build up, or to suspend chest movements during a critical recording session, etc.

The **MANUAL** push-button is useful for introducing sighs or other occasional hyperinflations. Note that these controls override all other ventilator controls, and can be used at any time regardless of ventilator mode settings.

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3.10 DATA INTERFACE

The **DATA PORT** on the rear panel provides access to a number of external control functions, and internal monitoring signals. The function of these connections on the AVS-1 is described below.

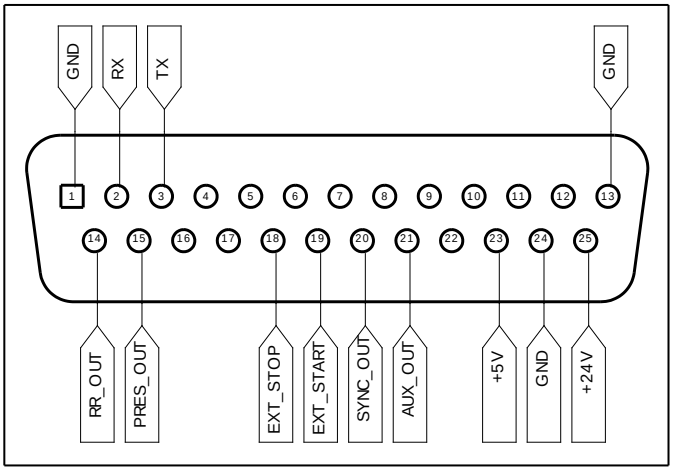

Figure 3: AVS-1Data Port connections

AVS-1 **DATA PORT** Connections:

SERIAL PORT (GND, RX, TX) — This provides a data set of the ventilator settings in a standard RS232 format: 9600,N,8,1

The data string is composed as follows:

120.9,10.999,10.5,CLOCK,TIME,<CR>,<LF>

This is read as: RR, TI, pressure setting, start mode, stop mode, followed by the carriage return and line feed characters ASCII 13 & 10. In addition, the stop mode may be followed by CO2 or AUTO if those modes are operating. Data is sent out every two seconds.

PRESSURE Output — Analog pressure signal, same scaling as the front-panel output

RESPIRATORY RATE Output — Analog signal, same scaling as the front-panel output

AUX OUT Output — future function

EXT START Input — same as front-panel input

EXT STOP Input — same as front-panel input

SYNC Output — TTL high during inspiration, low during expiration

POWER PINS (+5V, +24V, GROUND) — these voltages are available for custom use

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4.0 ORDERING INFORMATION

PART Nº	MODEL	DESCRIPTION
12-07000	AVS-1	Ventilator with one Valve Assembly (CTP-VA-1 or CTP-VA-3)
12-04000	CTP-VA-1	Solenoid Valve Assembly, mouse to Guinea pig size
12-05000	CTP-VA-3	Solenoid Valve Assembly, cat to small monkey size
12-10010	MVA-4	Electrical adapter for adding up to 4 external valve assemblies
12-10020	EFM-1	Flowmeter/regulator, with stand, specify range: 0.1, 1, 2.5, 5 l/min
12-10021	EFM-4	Flowmeter/regulator manifold w/ 4 flowmeters, with stand, specify range
11-10000	CapStar-100	End-tidal CO_2 Analyzer, complete with accessory pack, 115/230V (rat and larger)
15-10000	MicroCapStar	End-tidal CO_2 Analyzer, complete with accessory pack, 115/230V (mouse and larger)

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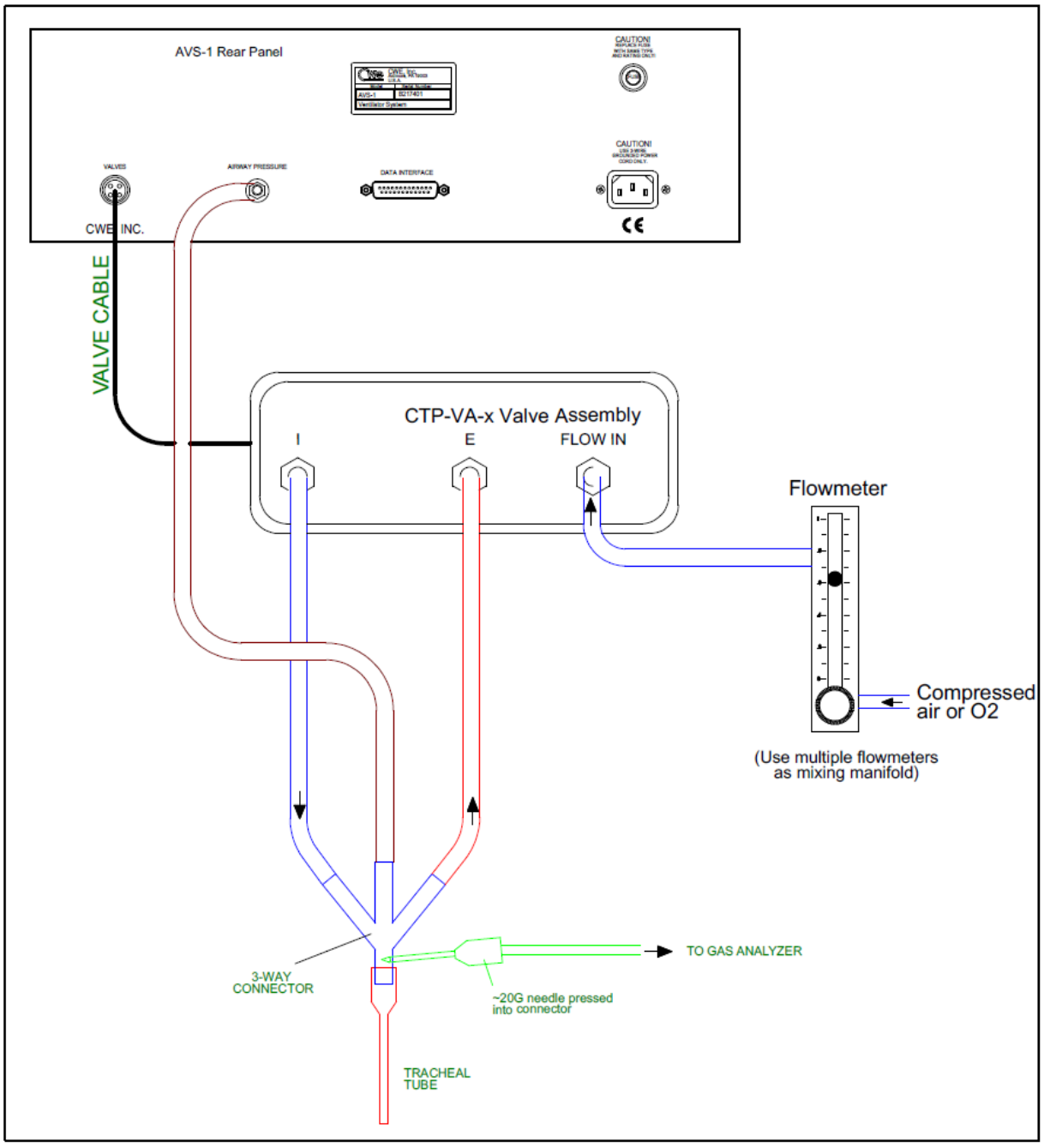

Figure 4: External Valve Assembly connection diagram

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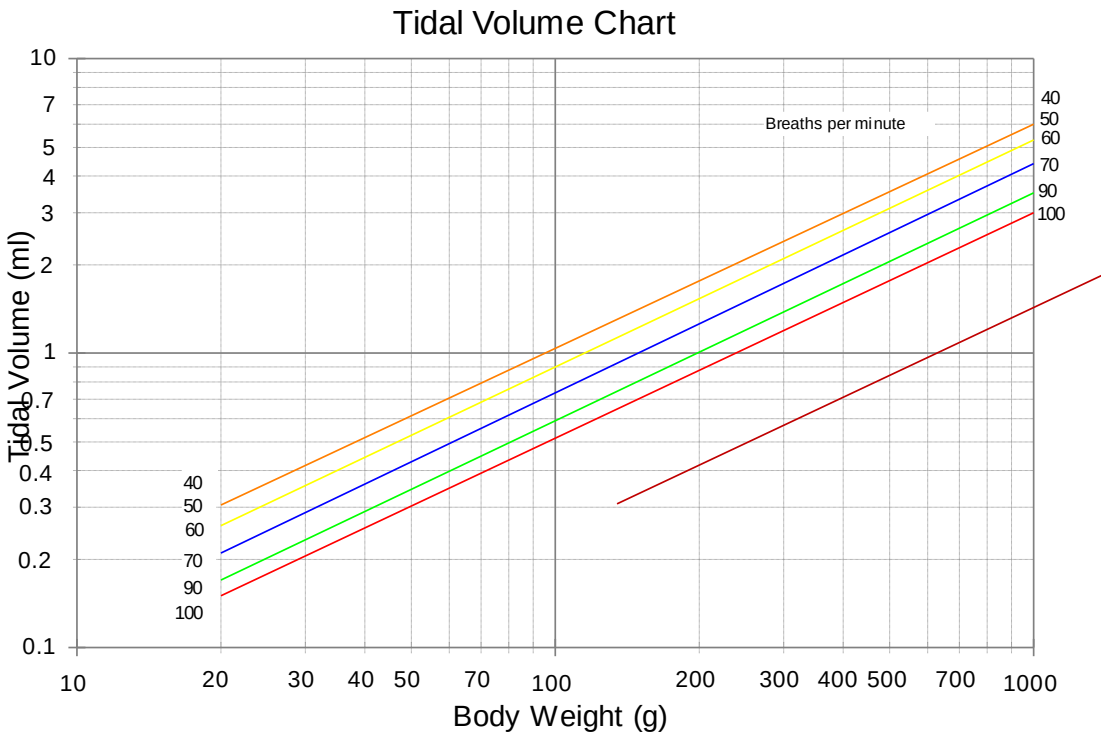
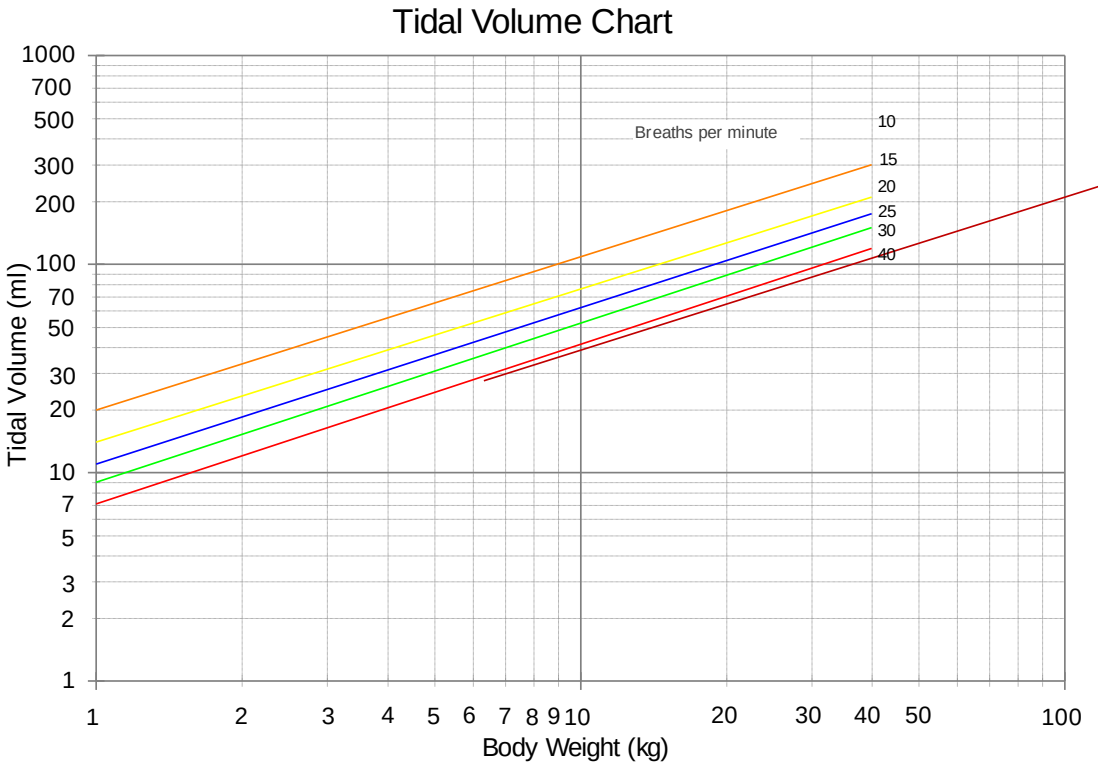
APPENDIX 1: TIDAL VOLUME VT) VS. BODY WEIGHT CHARTS





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APPENDIX 2: TYPICAL VENTILATOR SETTINGS FOR RODENTS

Weight (g)	VT (ml)	RR (bpm)	Flow (ml/m)	TI (s)	I:E (%)
25	0.15	120	45	0.200	0.4
100	0.61	90	136	0.267	0.4
200	1.22	80	244	0.300	0.4
350	2.15	60	322	0.400	0.4
500	3.08	50	385	0.480	0.4
1000	6.20	45	698	0.533	0.4
2500	15.64	35	1369	0.686	0.4

Note: Settings above are suggested guidelines. These are based on the following equations, with slight modifications owing to the difference between spontaneously breathing animals vs. mechanically ventilated ones. In general, ventilation is done at a lower rate than would be observed with in vivo awake animals. You will probably need to adjust the settings for your particular animal depending on its condition, anesthesia, or other factors.

VT = 0.0062 X MB ^1.01
RR = 53.5 X MB^-0.26
Where: VT is in liters, body mass (MB) is in kilograms

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