Ventilators are commonly used in the operating room and in the ICU to deliver mechanical ventilation to the lungs.Breath controlcomplexitygives rise to the needto identifyanddescribe "modes"ofventilation. Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 12 Multi-compartment model of the respiratory system connected to a ventilator using electronic analogs 2nd Semester 2023-2024 13 Assist Lec.: Athra'a Sabeeh 14 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Modern ventilatormachines have two separate but inter connectedsystems;apneumaticflowsystemandanelectronic controlsystem. Thepneumaticflowsystemenablestheflowofgasthroughthe ventilator.Thegases(oxygenandmedicalgradeair)enterthe air / oxygenmixer which they combine at the required percentage.Thegasesthenenteralargereservoirtanktobe compressed.Anelectronicallycontrolledflowvalveproportion thegasflowfromthereservoirtanktothepatient'sbreathing circuit. Insomeventilators,anaircompressorisusedinplace of acompressedair tank.Ventilatorsrequireelectricpower, oxygen, and compressed air usually supplied via external powersourceaswellasviahospital'scentralgassupply(with supplypressureofapproximately3-6bar). Inareaswithout centralgassupplyorduringtransportationofpatientswithin thehospital, it isnecessary toensurethe functioningof the devicebyothermeans.Potential solutions includetheuseof separate compressors, compressed gas cylinder packs, and accumulators. Ventilator Functional Block Diagram Gas mixer allowsthe user to vary theoxygen concentration of inspiratory gas between 21%and100%byvolume: a. Mechanical gas mixers(old technology). b. Electronically-controlled gas mixer integrated in ventilator(standard now). Gas mixers usually responsible for ensuring that breathing gas to be supplied is prepared and delivered in required quantity and rate. It is often the threshold ranges whichposethegreatest challenges to thesemeteringsystems. For volume of 20 mlwith an oxygen concentration of 30% by volume, 17.7 mlof gasmust be deliveredviacompressedair valveand2.3mlviaoxygenvalve. The pressure or flow generator is responsible for delivering mixed gas prepared by the gas mixer according to selected ventilation parameters. Flow generator is a controlled valve whose output provides defined gas flow with output pressure is not specified. Pressure generator behaves similar to compressor, whose output provides defined pressure with unspecified gas flow. It's often used to drive ventilators notdependentoncompressedairthat useambient air forventilation. 2nd Semester 2023-2024 Assist Lec.: Athra'a Sabeeh 15 Breathing System Breathing system forms interface between patient and the ventilator. Clinical ventilators are usually connected to patient via inspiratory and expiratory hose (dual-hose circuit). Expiratory valve is closed during the inspiratory phase where gas flow delivered through inspiratory portpasses through breathing gas humidifier before entering patient's lungs to make it adapted to climatic conditions in patient's lungs. After inspiratory phase, patient exhales when expiratory valve is opened, expiratory gas passes through ventilator again, but not reused for following inspiration. Based on this characteristic, the breathing systems of ventilators are also referred to as non rebreathing circuits. Gas Humidifier Humidifiers are used to warm and humidify inspiratory gas. Dry and relatively cool supply gas would dry out the patient's airways with risk of causing irreversible damage to the ciliated epithelium. Active gas humidifiers are located in the inspiratory limb and use electrical energy to heat a water bath. When the cold, dry gas passes over the water surface it absorbs water molecules and is thuswarmed and humidified. Example: Pass-over humidifiers and Bubble- through humidifiers. Passive breathing gas humidifiers, termed heat and moisture exchangers (HMEs), are placed close to patient and designed to buffer significant fraction of moisture and heat expired by patient. Retained moistureis then usedto conditioninspiredgas passingthrough HMEduringnextinspiration. 2nd Semester 2023-2024 Assist Lec.: Athra'a Sabeeh 16 17 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Expiratory (Exhalation) Valve Expiratory valve switches between inspiration and expiration phases of Ventilation If valve is not opened completely during expiration, positive end-expiratory pressure (PEEP) is created in lungs. PEEP is therapeutically important as it increases gas exchange surface oflungs. Adequate PEEP can also prevent collapse of individual alveolar areas. If expiratory valve is controlled during inspiratory phase, it can compensate for undesired pressure rises in breathing system Caused, for example, bypatient coughing. 2nd Semester 2023-2024 Assist Lec.: Athra'a Sabeeh 18 19 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 OperatingandDisplayUnit Operatinganddisplayunitistheinterfacebetweenventilatoranduser.Oftentouchscreensdesignedtodisplay pressureandflowcurvesaswellasmultiplemenusforsettingdifferentventilationmodes,adjustingalarmlimits ormeasuredvalueoverviews,etc.Parametersettingsenteredinoperatingunitcontroldevicecomponentsand thereforedetermineventilationpatternappliedtothepatient. AlarmSystemandPatientMonitor Ensuresthatventilationparametersset inoperatinganddisplayunitareactuallyapplied.Thissystemissues audibleandvisualalarmstoalertstaff tocritical changes inthepatient'sconditionor technicalmalfunctions monitorsthefollowing: 1. Inspiratoryoxygenconcentration(controlledbythegasmixer) 2. VentilationPressureandVolume(tomonitorthepressure/flowgenerator) 3. Inspiratorybreathinggastemperature(whenusingactivegashumidifier) Patientmonitoringisusedtomonitorthepatient'svitalfunctions 1. Electrocardiogram(ECG) 2. Bloodpressure(noninvasiveand/orinvasive) 3. Oxygensaturation 4. Carbondioxideconcentrationinthebreathinggas 20 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Modernventilatormachinesconsistoftwoseparatebutinter-connectedsystems:thepneumaticflowsystemand anelectroniccontrolsystem. Thepneumaticflowsystemenablestheflowofgasthroughtheventilator.Oxygenandmedicalgradeairenterthe ventilatorat3.5bar(50psi)pressurethroughbuilt-in0.1micronfilters.Thenormaloperatingrangeis2to6bar or28to86psi.Thesegassesenter theair/oxygenmixerwheretheycombineat therequiredpercentageand reducedinpressureto350cmH2O.Thegassesthenenteralargereservoirtankwhichholdsabout8litersof mixedgasses,whencompressedto350cmH2O.Anelectronicallycontrolledflowvalveproportionsthegasflow fromthereservoirtanktothepatientbreathingcircuit.Insomeventilators,anaircompressorisusedinplaceofa compressedairtank.Theprimaryobjectiveofthedeviceistoensureproperlevelofoxygenintheinspiratoryair anddeliveratidalvolumeaccordingtotheclinicalrequirements. Asthegassesleavetheventilator, theypassbyanoxygenanalyzer,asafetyambientairinletvalveandaback-up mechanicaloverpressurevalve.Theambientvalveprovidesthepatienttheabilitytobreatheroomairwhenthe ventilatorfailsorthepressureinthepatientcircuitdropsbelow-10cmofH2O.Inthepatientbreathingcircuitis abi-directionalflowsensortomeasurethegasflows.Theexhaledgassesexitthroughanelectronicallycontrolled exhalationvalve locatedat theventilator.With the introductionofmicroprocessors forcontrol ofmetering devices,electromechanicalvalveshavegainedpopularity.Themicroprocessorcontrolseachvalvetodeliverthe desiredinspiratoryairandoxygenflowsformandatoryandspontaneousventilation.Ahighpressurevalveisused toprovidesafetyincasethepressureinthepatientcircuitexceeds110cmH2O. Types of Ventilators ModernVentilators(Microprocessorcontrolled) The electronic control system may use one or more microprocessors and software to perform monitoring and control functions in a ventilator. These parameters include setting of the respiration rate, flow waveform, tidal volume, and oxygen concentration of the delivered breath, peak flow and PEEP. The PEEP selected in the mandatory mode is only used for controlof exhalation flow. The microprocessor utilizes the above parameters to compute the desired inspiratory flow trajectory. The system consists of monitors for pressure flow and oxygen fraction. The sensors are connected to electronic processing circuits which makes them available for digital readouts. The signals are also compared with pre-set alarm levels so that if they fall outside a pre-determined normal range, alarms are sounded. The pressure sensors are normally of semiconductor strain gauge typeplaced in a bridge configuration. For measurement of fraction of oxygen in the inspired air, afuel cell type oxygen sensor is used.This sensorgenerates acurrentproportionaltopO2. 2nd Semester 2023-2024 Assist Lec.: Athra'a Sabeeh 21 22 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Anewtechniqueforventilatingpatientsat frequenciesmuchhigher thantherespirationratehasrecentlybeen introduced.ThismethodhasbeenshowntoimproveCO2washoutandprovideadequateoxygenationwithoutthe requirementforhighinspiratorypressures.Thekeyprincipleinthistechniqueistoprovidetidalvolumesequalto orsmallerthanthedeadspace,atveryhighrates. Inconventionalpositivepressureventilation,CO2eliminationis directlycontrolledbytheamountofappliedminuteventilation.However,itisknownthatmeanairwaypressureis theparameterthatbestcorrelateswithimprovementinoxygenation.Gastransportduringconventionalventilation isattributed totwobasicmechanisms: (i)convectionor flowof gas throughtheconductingairways, and(ii) moleculardiffusionof gasses intothealveoli andpulmonarycapillaries. Thetidalvolume(VT)applied tothe patientattheY-piececanbedividedintothevolumeusedtoventilatethedeadspace(VD)andthealveolarvolume (VTalv).Onlythealveolarvolumetakespartinthegasexchangeprocess.Therefore, HighFrequencyVentilators

V Talv=VT-VD

Theportionofthetidalvolumeusedtoventilatethedeadspacedoesnottakepartincapillarygasexchangeandis thereforewasted. Toovercome theproblemofwastedventilation inconventionalventilation, the inspiratory pressureisincreasedinordertoincreasethetotal tidalvolume.Unfortunately,however, thisalsoincreasesthe mechanicalstressonthelungandhasbeenassociatedwithvarioustraumas.Highfrequencyventilationhasbeen showntoprovideadequatealveolarventilationandoxygenationwithout therequirement forhighinspiratory pressures.Theventilatorgenerateshighfrequencyratefrom5to20Hz(300to1200pulse/minute).Although severalmethodsareavailabletogeneratethehighfrequencypressurewaves, theBabylog8000makesuseofan oscillatingdiaphragmmechanism. 23 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Thismechanismis computer-controlled and canpreciselydetermine the shape of thepressure swings. An alternativemethodofachievingHFventilationisbasedonthejetprincipleinwhichasmalldiametertubeispassed downatrachealcannulaandiseitherterminatedatitsdistalendorextendedintothetracheaitself.Shortpulsesof higherpressureoxygenareintroducedintotheairwaythroughthecannulaatfrequencieswellabovethenormal respirationrate.Thistechniquehasthedisadvantageofforcingvolumeintothepatientandthenleavingthepatient toexhalepassively,whichmayleadtosometrappedvolumeinsidethelungincreasingthemeanlungpressure. Thisproblemisovercomebyensuringthatthepressureduringtheexhalationphaseisnegativewithrespecttothe setPEEP. 24 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024

Themaintaskofahumidifieristoreplacehumidityintheupperairpassageswhichhasbeenlostbyintubation. Thehumidityshouldbeascloseto100%aspossible,orspeakingintermsofwater,theabsolutecontentperliter breathinggasshouldbemorethan30mg,regardlessofenvironmentalconditions.Therefore,inordertoprevent damagetothepatient'slungs,theairoroxygenappliedduringrespiratorytherapymustbehumidified.Thus,all ventilatorsincludearrangementstohumidifytheair,eitherbyheatvaporization(stream)orbybubblinganair streamthroughajarofwater.Whenwaterorsometypeofmedicationsuspendedintheinspiredairasan aerosol istobeadministeredtothepatient, adevicecalledanebulizer isused. Inthisdevice, thewateror medicationispickedupbyahighvelocityjetofair/oxygenandmadetoimpactagainstoneormorebafflesto breakthesubstanceintocontrolled-sizeddropletswhicharethenappliedtothepatientviaarespirator.More effectiveandefficientnebulizersarebasedontheuseofhighintensityultrasoundenergywhichvibratesthe substance(waterormedication) toproduceahighvolumeofminuteparticles.Ultrasonicnebulizersdonot dependuponbreathinggasforoperationandthustherapeuticagentscanbeconvenientlyadministeredduring ventilationprocedure.Aspiratorsareoftenincludedaspartofaventilator toremovemucusandotherfluids fromtheairways.Alternatively,aseparatesuctiondevicemaybeutilizedtoachievethesamepurpose. Humidifiers,NebulizersandAspirators 1. Breathing pattern I.VolumeControl (VC) Aventilator canbeclassifiedas either a pressure, volume, or flow controller. When classifyingmodesof ventilation, we do not need to be so specific. Because control of volume implies control of flow andviceversa,wecanrefer to twobasicmodesofventilation: volume control and pressure control. II. Pressure Control (PC) Pressure controlmeans that the airway pressure waveform is preset (for example by setting peak inspiratorypressureandend expiratory pressure). Tidal volume and inspiratory flow are then dependent on these settings and the elastance and resistance of therespiratorysystem. Dual Control (DC) There are clinical advantages and disadvantages to volume and pressure control. Simply put, volume control results in amore stableminute ventilation (and hence more stable gas exchange) than pressure control if lung mechanics are unstable. On the other hand, pressure control allows better synchronizationwith thepatient because inspiratoryvolumeand floware not limited to arbitrary preset values. While it ispossibletocontrol only one variable at a time, a ventilator can automatically switch between pressure control andvolume control in an attempt to guarantee minute ventilation while maximizingpatientsynchrony. 25 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Modes of Ventilation A. Primary breath control variable 26 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Therearetwotypesofdualcontrol.Dualcontrolbetweenbreathsmeansthattheventilatorcontrolspressure duringeachbreathbut adjusts thepressure limit toachievea tidal volume target over several breaths. Alternatively, theventilatorcanswitchbetweenvolumeandpressurecontrolduringasinglebreath(dual controlwithinbreaths,figurebelow). Modes of Ventilation 1. Breathing pattern B. Breath sequence The second component of the breathing pattern specification is the breath sequence. A breath is defined as a positive change in airway flow (inspiration) paired with a negative change in airway flow (expiration), both relative to baseline flow and associated with ventilation of the lungs. But the definition allows the superimposition of, say, a spontaneous breath on a mandatory breath or vice versa. On the other hand, mandatory breaths are superimposedonspontaneousbreaths during high-frequencyoscillatoryventilation. The classification of modes requires the definition of two basic types of breaths: spontaneous and mandatory. A spontaneous breath is a breath for which the patient controls the start time and the tidal volume. That is, the patient both triggers (starts) and cycles (ends) the breath. A spontaneous breath may either beassistedor unassisted. A mandatory breath is a breath for which the machine sets the start time and/or the tidal volume. That is, the machine triggers and/or cyclesthe breath. 2nd Semester 2023-2024 27 Assist Lec.: Athra'a Sabeeh there are three possible sequencesof breaths, designatedas follows: I. ContinuousMandatory Ventilation (CMV): all breaths are mandatory II. ContinuousSpontaneous Ventilation (CSV): all breaths are spontaneous III. Intermittent Mandatory Ventilation (IMV): breaths can be either mandatory or spontaneous.Breaths can occurseparately or breaths can be superimposedon each other. When the mandatory breath is patient-triggered, it is commonly referred to as synchronized IMV (SIMV). However, because the trigger variable can be specified in the description of phase variables, we will use IMV instead ofSIMVto designate generalbreath sequences. When we add the breath sequence to the control variable in classifying a mode, we get a greater ability to discriminate modes. We can distinguish between, say, pressure controlled IMV and pressure controlled CSV. If we confine ourselves to classifying modes based solely on the breathing pattern, we see that there are only eight possibilities: VC-CMV, VC-IMV, PC-CMV, PC-IMV, PC-CSV, DC-CMV, DC-IMV, and DC-CSV. Note that VC-CSV is impossible by definition. 2nd Semester 2023-2024 Assist Lec.: Athra'a Sabeeh 28 29 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024

Wehavediscussed"controlvariables"andthedifferencesbetweenpressure,volume,anddualcontrolbut,we havenotreallyexplainedwhatismeantby"control"inthefirstplace.Therearetwogeneralwaystocontrola variable;openloopcontrolandclosedloopcontrol.The vast majority of ventilators used in the world provide "conventional" ventilation. This employs breathing patterns that approximate those produced bya normal spontaneouslybreathing person. 2nd Semester 2023-2024 6 Assist Lec.: Athra'a Sabeeh 7 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 Automating Ventilator Lung Volume and Capacity Volumes:There arefourvolumes: (1) tidal volume(Vt) is the volumeofgasinhaled or exhaled duringeach respiratorycycle. (2) inspiratoryreservevolume(IRV)is the maximalvolumeofgas inspiredfromend-inspiration. (3) expiratoryreservevolume(ERV)is the maximalvolumeofgasexhaled fromend-expiration. (4) residualvolume(RV)is the volumeofgas remainingin the lungsfollowingamaximalexhalation. Capacities:There are four capacities, each of which contains two or more primary volumes: (1) total lung capacity (TLC) is the amount of gas contained in the lung at maximal inspiration. (2) vital capacity (VC) is the maximal volume of gas that can be expelled from the lungs by a forceful effort following maximal inspiration, without regard for the time involved. (3) inspiratory capacity (IC) is the maximal volume of gas that can be inspired from the resting expiratory level. (4) functional residual capacity (FRC) is the volume of gas in the lungs at resting end-expiration. Tidal volumes are large enough to clear the anatomical dead space during inspiration and the breathing rates are in the range of normal rates. Gas transport in the airways is dominated by convective flow and mixing in the alveoli occurs by molecular diffusion. There is also a class of "high frequency ventilator" that delivers tidal volumes less than dead space volume at frequencies up to 15 Hz. High frequency ventilators, in theory, minimize the risk of damage to diseased lung tissue that could be caused by volumetric over distention with normal tidal volumes.Control Type Description ExampleControl Scheme ExampleMode Example Ventilator Setpoint Outputmatchesfixedinput Tidalvolumeorpeak pressureheldconstantby adjustingcontrolvariable Pressurecontrol Assist control Pressuresupport SiemensServo Hamilton Galileo PB840 Servo Outputmatchesdynamic input Pressuremade proportionalto volume and/orflow Proportional Assist Automatic Tube Compensation NotavailableinUS DragerEvita4 Setpoint Dual Control Automaticswitchbetween pressureandvolumecontrolto maintain operator defined setpoint Volume control overrides pressurecontrolwith breathifsettidalvolume notmet PressureLimited Ventilation Volume Assured PressureSupport DrigarEvita4 Bird8400ST Adaptive DualControl Automaticadjustmentof pressuresetpointtomaintain anoperatorselectedvolume setpoint Pressure limit adjusted to maintain set tidal volume, using lungmechanics Pressure Regulated Volumecontrol AutoFlow SiemensServo300 DragerEvita4 Optimal Dual Control Automatic adjustment of both pressure and volume setpointto minimizeothervariables Pressurelimitandtidal volume adjustedtominimize workofbreathing,usinglung mechanics AdaptiveSupport Ventilation HamiltonGalileo 32 Assist Lec.: Athra'a Sabeeh 2nd Semester 2023-2024 A.Thephasevariable isasignal that ismeasuredandusedbytheventilator toinitiatesomepart, or phase, of thebreathcycle.Thevariablecausingabreathtobeginis thetriggervariable.Avariablewhose magnitudeisconstrainedtosomemaximumvalueduringinspirationiscalledalimitvariable.Thevariable causingabreathtoendisthecyclevariable.Duringexpiration,theventilatorusuallymaintainssomelevelof pressureatoraboveatmosphericpressure,whichisreferredtoasthebaselinevariable.Thus, to understand ventilators wemustfirstunderstandtheirfourmechanical characteristics: 1) Inputpower 2) Powerconversionandtransmission 3) Controlsystem 4) Output(pressure,volume,andflowwaveforms) The physical model (Pneumatic model) of breathing mechanics most commonly used is a rigid flow conducting tube connectedto anelastic compartment.?Thesimplestmechanical devicewecouldadvise to assistaperson'sbreathingwouldbeahand-driven, syringe-typepumpthat isfittedtotheperson'smouth andnoseusingamask.Avariationof thisistheself inflating, elastic resuscitation bag.?Open loopcontrol isessentiallynocontrol.2.?2.3.