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Concept of Pulmonary Dialysis and Component Dialysis: A Triumph Over Mechanical Ventilation & Conventional Dialysis

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Abstract

Pulmonary dialysis is a new concept and a good alternative to conventional mechanical ventilation of lung. Details of this concept have been reported in a book "The concept and design of intra-vascular access based mechanical ventilation of lung", published in 2020. On the basis of "The theory of relative stability" in 2016, an upgraded version of mechanical organ support can be developed. Here in this article, design and diagram of a newly proposed ventilator system, is going to be reported for pulmonary support, which is equally effective even in complete dysfunction of lungs. Therefore, the situation of planned "artificial lung de-functioning" can be achieved for therapeutic purpose. Moreover, it is a triumph over the conventional mechanical ventilation and organ support in ICU. In addition to this, artificial organ support for other organs (renal, hepatic etc.) can be also developed eventually. Moreover, any component or element in body fluid can be dialyzed based on this principle (component dialysis). Beginning of a new era is the effect.

Keywords: *Mechanical ventilation, the theory of relative stability, ICU support, homeostasis, pulmonary dialysis, component dialysis.*

Background

In 2016, a new theory of homeostasis has been declared regarding the very basic and fundamental principle of universal stability (1, 2). Based on this principle, a new system of artificial ventilation is being created (3, 4). This updated modality of artificial ventilation is not lung based, rather intravenous access based. Ventilation clinical practice guidelines in adults with COVID-19 were released by the European Society of Intensive Care Medicine and the Society of Critical Care Medicine (5) recently. Especially among those patients, in this very COVID 19 situation, this is perhaps a revolution for ventilatory and other organ support.

Introduction

A very basic rule of maintaining equilibrium and stability has been described in "The theory of relative stability" (1, 2). Using this principle homeostasis of human body, organ function, normal physiology as well as patho-physiology of disease process can be described (3, 4). Mechanical organ support is an import aspect of modern ICU management. And in this very "COVID-19" crisis, up-gradation of mechanical support is a very sensitive issue. In this regards, improvement of mechanical organ support can be achieved by the principle of "The theory of relative stability". Replacing or de-functioning devices of renal function, hepatic function, maintaining of blood sugar by making "Glucostat device" and so on is quite possible by applying this principle. Moreover improvement of existing concept and machineries of ICU and organ support is also possible by using this new theory (3, 4).

Here in this article, design of such an upgraded model (as an example) of ventilator support to maintain the

pulmonary function is going to be presented here for justification.

Unique Advantage Over Conventional Mechanical Ventilation (6)

1. As the proposed ventilation system is intra-vascular access based (rather mechanical lung based), therefore, total de-functioning of the lung is possible.

2. In un-salvable case of lung trauma or lung pathology, salvage of the patient is possible.

3. As complete de-function is possible, thus extensive pulmonary & mediastinal and thoracic surgery is possible.

Crude Design (3, 4, 6)

This special device has two reservoir chambers, R1 and R2 and variable numbers of individual equilibrium units, such as- oxygen equilibrium unit, carbon dioxide equilibrium unit, dialysis unit or other additional units according to the requirements.

The input channel attached to the R1 chamber has side channel, a flow pump (Pa) and an anticoagulant pump (Ap) serially in a row and the output channel attached to the R2 chamber has a side channel (Sc), the expandable portion (Ep), a bubble tap (Bt) and a flow pump (Pz) also serially in a row.

The rate of inflow and outflow through the input pump (Pa) and output pump (Pz) is equal correspondingly.

There are variable numbers of connecting channels and pumps in this special device depending on the number of equilibrium units.

This special device may be attached to variable numbers of equilibrium units based upon the requirements.

a) Air- Blood Exchange Unit

Exchange and equilibrium occur between air and blood

- Oxygen equilibrium unit
- Carbon dioxide equilibrium unit
- Other units

b) Liquid- Blood Exchange Unit

Exchange and equilibrium occur between liquid and blood

- Dialysis unit
- Other units

Oxygen Equilibrium Unit

It consists of:

- Exchange chamber (E chamber)
- Adding chamber (A chamber)

There are two connecting channels in between these two chambers. Each channel has a time dependent pump with equal flow rate.

When blood passes through the exchange chamber, for each cycle of flow, the partial pressure of oxygen in blood becomes half and then passes through "A chamber" where a fixed amount of oxygen is added in each cycle.

This recycling of blood between the "E" and "A" chambers occurs for a desirable previously calculated definitive number of cycles.

After the definitively numbers of recycling, the partial pressure of oxygen in the blood becomes fixed to the previously calculated fixed desirable level.

Exchange Chamber (E Chamber)

Each equilibrium unit must have at least one exchange chamber, but may have more.

"The more the number of exchange chambers, the more the functional capacity of the device."

Each exchange chamber must have at least two layers of exchange blocks, preferably 3 or more.

"The more the number of layers, the more the number of exchange blocks, the more the functional capacity of the device."

The number of exchange blocks in relation to number of layers is given in table 1.

Table1. *The number of exchange blocks in relation to number of layers.*

Layer number	Total exchange block number
1	1
2	5
3	16
4	28

Adding Chamber (A Chamber)

Adding chamber may be one or many depending upon the number of exchange chamber.

The number of adding chamber should be equal to the number of exchange chamber.

The structural frame and units of adding chamber is almost same as those of exchange chamber where the ultimate function is to add a fixed previously calculated amount of gas or substance within the blood.

Carbon Dioxide Equilibrium Unit

This is an air- blood exchange unit.

The basic structure, functions and other aspects of this unit are almost same as those of oxygen equilibrium unit.

Dialysis Unit

This is a liquid- blood exchange unit.

The basic structure, functions and other aspects of this unit are almost same as those of oxygen equilibrium unit based upon the basic principles of dialysis.

Others Units

May be a air- blood or a liquid- blood exchange unit depending upon the requirements.

The basic structure, functions and other aspects of this unit are almost same as those of oxygen equilibrium unit.

Pumps

The number of pumps is extremely variable depending upon the number of equilibrium units attached to the device.

The rate of flow through input pump (Pa) and output pump (Pz) is equal.

The flow rate through other pumps should be equal to one another (except to Pa and Pz).

Here, the important thing is that each pump of this device is time gated. The time dependency is equal for Pa and Pz. For other pumps, they are also time dependent to one another that is each pump is activated only after a previously calculated pre-set period of time.

Channels, Valves and Direction of Flow

Blood flow through channels is only unidirectional with valves in regular favorable pre-calculated fixed distance.

Input Channel

The input channel is attached to a side channel (Sc 1), a flow pump (Pa) and an anticoagulant pump (Ap).

Side channel attached to the input channel is for collection of blood sample, investigations and continuous monitoring.

Side channel 1 has a one way valve near its end through which blood can only be collected by active tension.

Output Channel

Output channel is attached with a side channel (Sc 2), a expandable portion (Ex), a bubble tap (Bt) and an output pump (Pz) in a row.

There is a one way valve at the entry point of the side channel (Sc 2) where only active entry under pressure is possible.

Drugs, fluid and other infusion can be given through the side channel.

There is also a one way valve in the output channel just proximal to the entry of side channel (Sc 2).

Expandable Portion of Output Channel

When infusion (fluid or parental nutrition) or drug is given through the side channel, this expandable portion expands and acts as a temporary reservoir for infusion or drug.

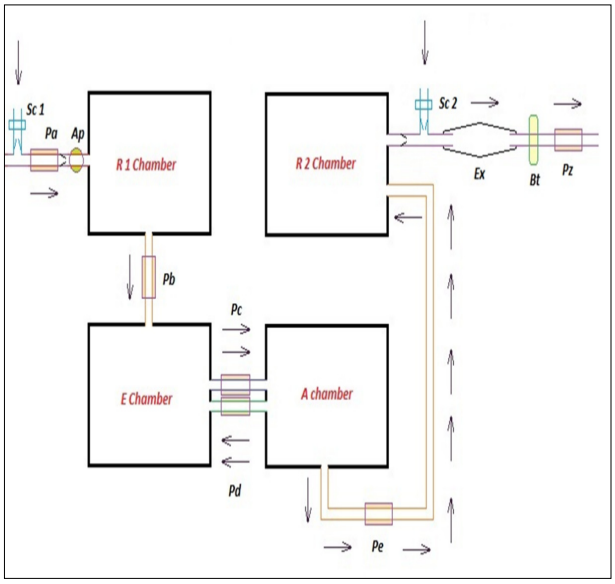


Figure1. *Integrated design proper (6).*

Abbreviations

R1 Chamber = Reserve Chamber 1

E Chamber = Exchange Chamber

A Chamber = Adding Chamber

R2 Chamber = Reserve Chamber 2

Pa – Pz = Pump a – z

Ap = Anticoagulant pump

Bt = Bubble tap

Sc 1 = Side channel 1

Sc 2 = Side channel 2

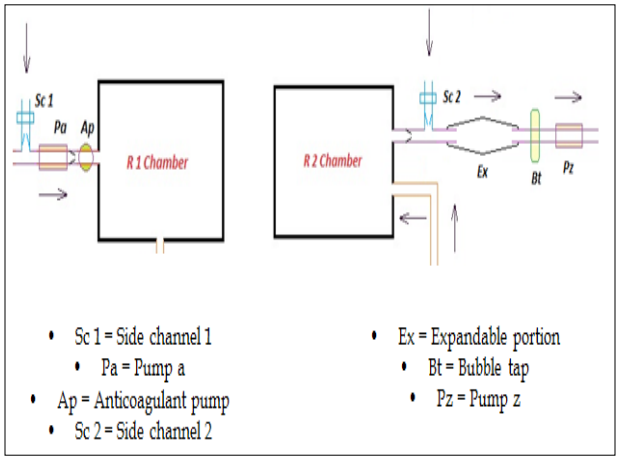


Figure2. *Input and output channels.*

Basic Structure of Equilibrium Unit

Each equilibrium unit has more or less common basic structural components such as E and A chambers, connections and pumps.

Depending upon the air- blood or liquid- blood exchange unit or upon the purpose, there may be basic structural and functional differences between individual equilibrium units.

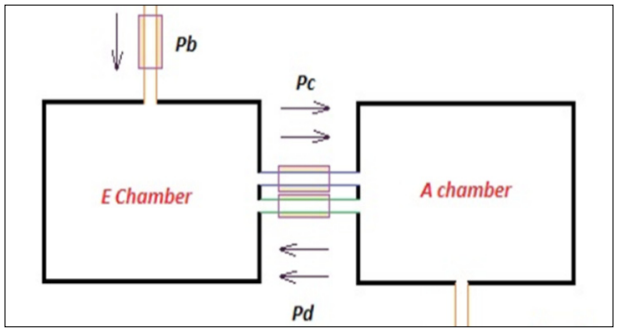


Figure3. E & A chamber

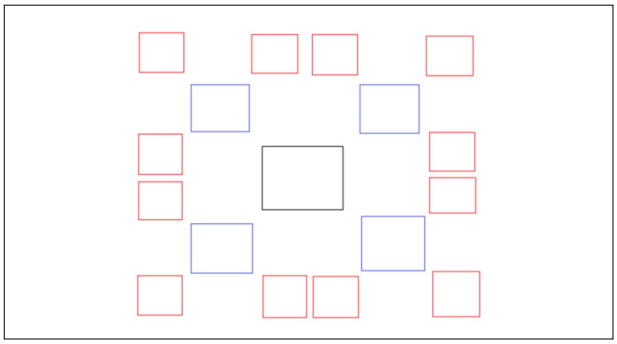


Figure4A. *Positions of 3 layered exchange blocks within exchange chamber (3 layers, layers may be more).*

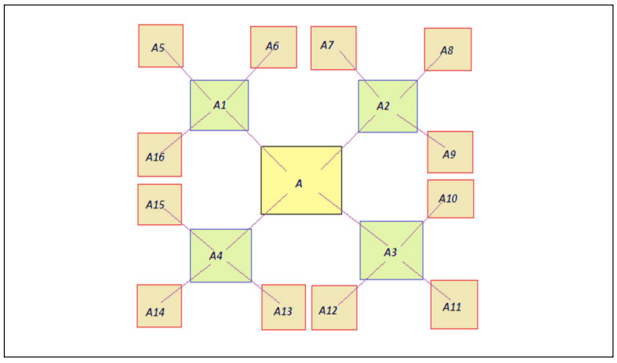


Figure4B. *First layer- A, second layer A1 to A4, third layer A5 to A16 (total 17 blocks in three layers)[6]*

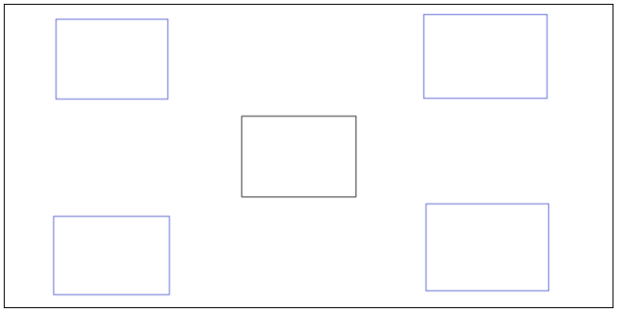


Figure4C. *Positions of exchange blocks in a two layered exchange chamber (first and second layers- A to A4).*

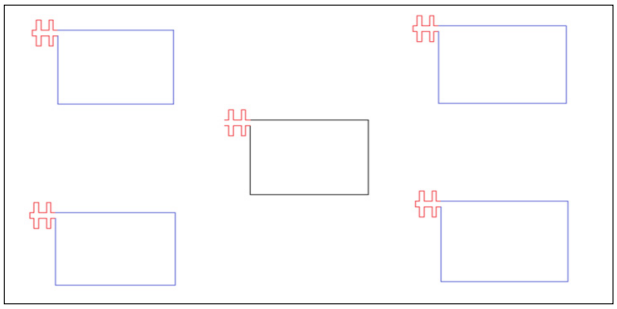


Figure4D. *Exchange blocks in 1st and 2nd layer with inflow connecting points.*

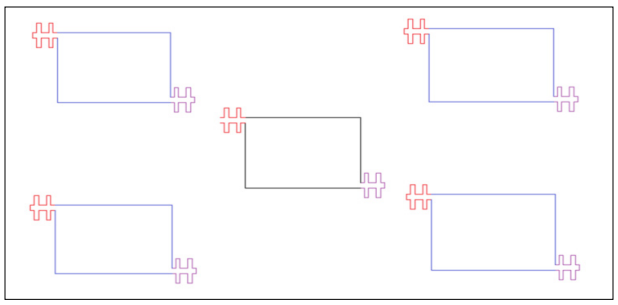


Figure4E. *Exchange blocks in 1st and 2nd layer with inflow and outflow connecting points.*

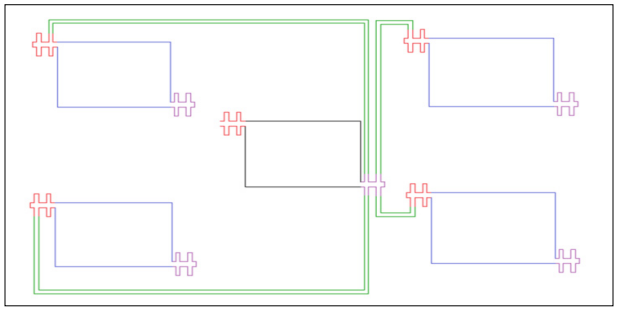


Figure4F. *Outflow channels connectivity between central and peripheral blocks in exchange chamber in 1st and 2nd layer.*

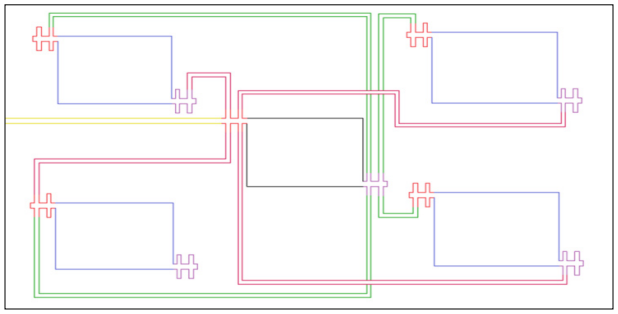


Figure4G. *Outflow and inflow channels connectivity between central and peripheral blocks in exchange chamber in 1st and 2nd layer (overall connectivity between blocks).*

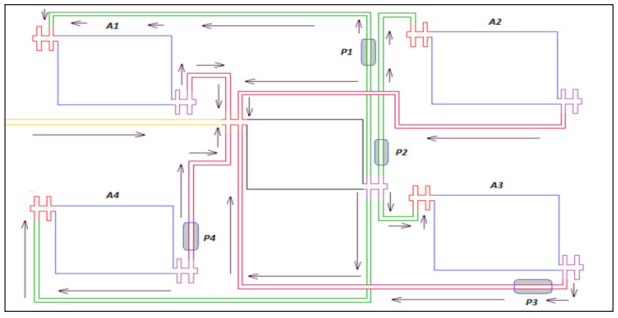
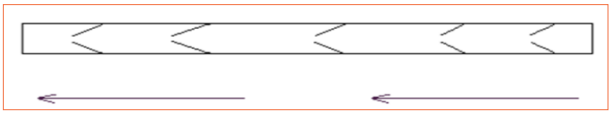


Figure4H. *Direction of blood flow through one way valves within connecting blocks with pumps (P1 to P4).*

Each exchange block within the exchange chamber has inflow and out flow connecting channels through which blood flow is only unidirectional.

In a two layered exchange chamber, the connecting channel is gated by 4 flow pumps (P1- P4) at 4 different points which is time dependent and also unidirectional.

Direction of Blood Flow through One Way Valves Within Connecting Channels



Each inflow and outflow connecting channel has several one way valves at certain frequent regular distance to make the flow only unidirectional.

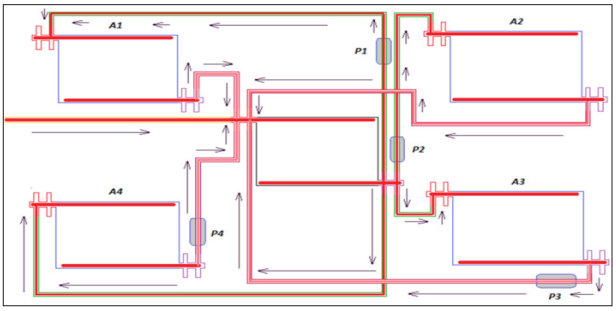


Figure5A. *One way direction of blood flow through valves within connecting channels.*

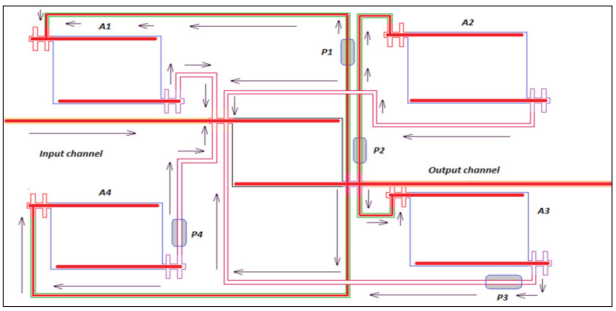


Figure5B. *Direction of blood flow through connecting blocks with output channel.*

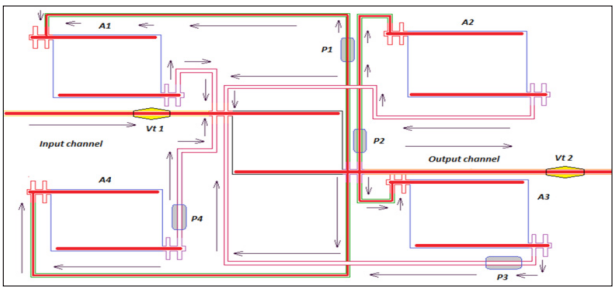


Figure5C. *Direction of blood flow through connecting blocks with time dependent pumps (Vt 1 and Vt 2) in input and output channel.*

Exchange Blocks

Depending on whether it is air- blood or liquid- blood exchange unit, exchange blocks are of two types:

- Gas exchange block
- Molecule exchange block

Gas Exchange Block

Gas exchange block is the structural as well as functional unit of this device.

Each block has variable number of gas exchange tubes through which blood flow at a regular rate only in one direction and consists of a fixed number of exchange units.

For each exchange tube, there is a gas transport tube parallel to it. Each gas transport tube is attached to a fixed number of gas exchange unit which projected within the gas exchange unit from the roof.

The total number of gas exchange tubes within an exchange block is equal to the number of gas transport tubes (both have same total volume also).

There are extensive multi-directional connections between the gas transport tubes, but blood flow through the gas exchange tubes is exclusively unidirectional.

In case of liquid- blood exchange equilibrium unit, the "gas exchange block" is termed as "molecule exchange block."

Molecule Exchange Block

In case of liquid- blood exchange unit, the gas transport tubes are replace for liquid transport tube through which a fixed volume of fluid is infused after a regular fixed interval and removed.

Molecule exchange occurs between transported fluid and blood through the special type of semi-permeable membrane.

Exchange Unit

Depending upon the previously mentioned criteria, it is of two types:

- Gas exchange unit
- Molecule exchange unit

Gas Exchange Unit

It is the basic unit where gas exchange takes place through special type of semi-permeable membrane at a regular rate.

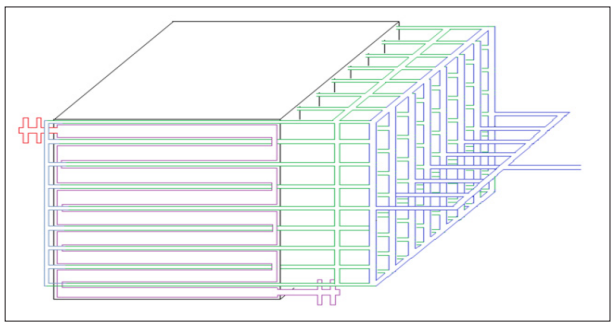


Figure6A. *Single exchange block with gas exchange tubes without exchange unit.*

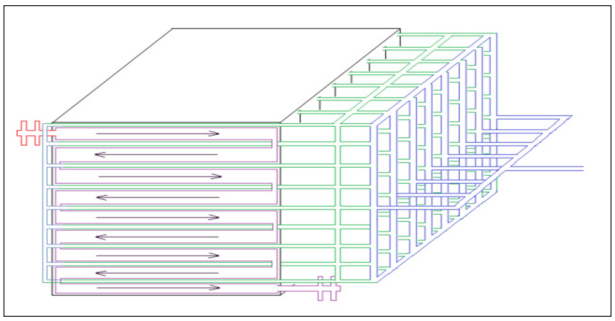


Figure6B. *Single exchange block with gas exchange tube without exchange unit with direction of flow.*

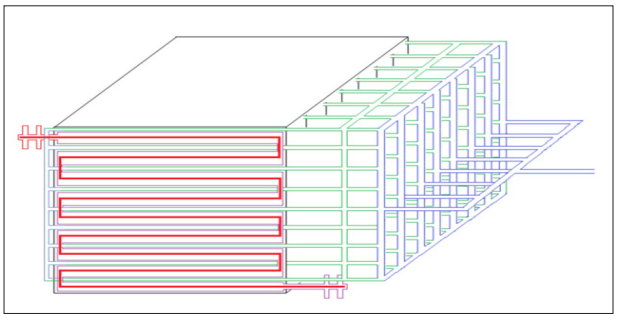


Figure6C. *Single exchange block with gas exchange tube without exchange unit with direction of flow.*

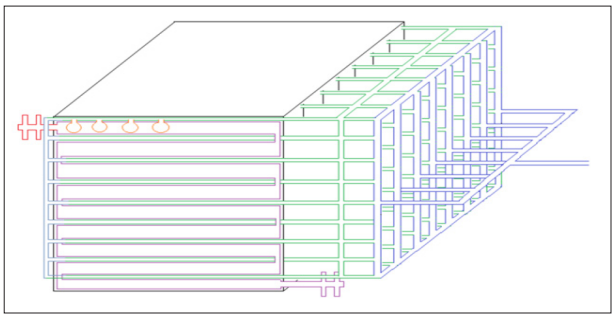


Figure6D. *Single exchange block with gas exchange tube with exchange units (which is fixed in number in each row- only first 4 are drawn here).*

Figure7. *Exchange unit-Gas exchange block.*

Reference ranges of ABG analysis

- pH= 7.36- 7.44
- pCO2= 85-95 mmHg
- pO2= 38-42 mmHg
- [Bicarbonate ion]= 21-27mEq/L

Example and Calculation

For the specific basic pattern of the series of serial sequential and repetitive equation/ reaction is: "{(Z_1+a) ÷x+y}", it can be said that (from this hypothesis):

$$z=\frac{xy}{(x-1)}$$

Let us think that we want to maintain pCO2 constantly approximately around at 40 mmHg, so, here Z=40.

If we use gas in the gas transport where pCO2 is zero (the volume of blood in gas exchange tubes and the volume of air in the gas transport tube should be equal), then after a certain period of time (due to exchange through the semi-permeable membrane), pCO2 in the transported blood will be just half to its initial value, so, here, x= 2.

Now the value of y=?

Now, if we place the values of "Z" and "x" in the previously mentioned equation, then we have the value of "y"

In this situation the value of "y" from calculation is 20.

So, if "x" = 2 and "y"= 20 remain unchanged, then the value of "Z" after a relative fixed number of repeated cycles, will be always fixed approximately around at the desirable value of 40 mmHg.

Let us think of some abnormal values of partial pressure of carbon dioxide (which may or may not be clinically relevant, but taken for understanding the calculation).

1st abnormal value of pCO2

pCO2= 80 mmHg

1st cycle: 80÷2+20= 60

2nd cycle: 60÷2+20= 50

3rd cycle: 50÷2+20= 45

4th cycle: 45÷2+20= 42.5

5th cycle: 42.5÷2+20= 41.25

6th cycle: 41.25÷2+20= 40.625 (Near to 40)

7th cycle: 40.625÷2+20= 40.3125 (More near to 40)

After repeated cycles: Z is approximately 40 mmHg.

2nd abnormal value of pCO2

pCO2= 68 mmHg

1st cycle: 68÷2+20= 54

2nd cycle: 54÷2+20= 47

3rd cycle: 47÷2+20= 43.5

4th cycle: 43.5÷2+20= 41.75

5th cycle: 41.75÷2+20= 40.875 (Near to 40)

6th cycle: 40.875÷2+20= 40.4375 (More near to 40)

7th cycle: 40.4375÷2+20= 40.40.3187 (More near to 40)

After repeated cycles: Z is approximately 40 mmHg.

3rd abnormal value of pCO2

pCO2= 200 mmHg

1st cycle: 200÷2+20= 120

2nd cycle: 120÷2+20= 80

3rd cycle: 80÷2+20= 60

4th cycle: 60÷2+20= 50

5th cycle: 50÷2+20= 45

6th cycle: 45÷2+20= 42.5

7th cycle: 42.5÷2+20= 41.25

8th cycle: 41.25÷2+20= 40.625 (Near to 40)

9th cycle: 40.625÷2+20= 40.3125 (More near to 40)

After repeated cycles: Z is approximately 40 mmHg.

4th abnormal value of pCO2

pCO2= 10 mmHg

1st cycle: 10÷2+20= 25

2nd cycle: 25÷2+20= 32.5

3rd cycle: 32.5÷2+20= 36.25

4th cycle: 36.25÷2+20= 38.125

5th cycle: 38.125÷2+20= 39.0625

6th cycle: 39.0625÷2+20= 39.5312 (Near to 40)

7th cycle: 39.5312÷2+20= 39.7656 (More near to 40)

After repeated cycles: Z is approximately 40 mmHg.

5th abnormal value of pCO2

pCO2= 27 mmHg

1st cycle: 27÷2+20= 33.5

2nd cycle: 60÷2+20= 36.75

3rd cycle: 50÷2+20= 38.375

4th cycle: 45÷2+20= 39.1875

5th cycle: 42.5÷2+20= 39.5937 (Near to 40)

6th cycle: 41.25÷2+20= 39.7969 (More near to 40)

7th cycle: 40.625÷2+20= 39.8984 (More near to 40)

After repeated cycles: Z is approximately 40 mmHg.

6th abnormal value of pCO2

pCO2= 00 mmHg

1st cycle: 00÷2+20= 20

2nd cycle: 20÷2+20= 30

3rd cycle: 30÷2+20= 35

4th cycle: 35÷2+20= 37.5

5th cycle: 37.5÷2+20= 38.75

6th cycle: 38.75÷2+20= 39.375 (Near to 40)

7th cycle: 39.375÷2+20= 39.6875 (More near to 40)

8th cycle: 39.6875÷2+20= 39.8438 (More near to 40)

After repeated cycle: Z is approximately 40 mmHg.

Key Point of Calculation

As long as "x"= 2 and "y"= 20, after a series of serial sequential and repetitive of cycles, "Z" is always approximately 40 mmHg, irrespective of the initial value.

It is also applicable to maintain any other substance levels (pO2, dialysis etc.) on the basis of requirement by adding respective equilibrium unit to this device.

Site for Placing Connection to the Body (6)

There are several sites where this external device can be connected to human body. But, to my mind, the best possible site (the superior vana cava) may be achieve by central venous access (preferably) by a special type of catheter.

Though, it can be done either by central or by peripheral venous access, central venous access is preferable.

It can be preferably done through subclavian (or internal jugular) vein.

Special Venous Catheter (6)

This special venous catheter has 5 channels, 3 balloons within it.

3 channels (inflation channel) within the lumen of the catheter are for inflation of individual balloon.

1 channel (input channel of catheter where output channel of the main equilibrium device is connected) extended within the lumen of the catheter from outside to the tip of the catheter.

1 channel (output channel of catheter where input channel of the main equilibrium device is connected) within the lumen of the catheter is extended from outside end of catheter to the distal balloon.

Output channel has got 3 openings (eyes) just proximal to the 3 balloons (one before each balloon).

When any of the balloons gets distended with air, then the output channel becomes block at that point and only the proximal eye remains open and collects blood at a fixed rate essentially equal to the flow rate of input channel.

This special catheter has 3 balloons at calculated regular distance, but number of balloons may be more.

After a regular period of interval (may be few hours, such as 12-24 hours), only one balloon (alternatively) gets distended when the rest remain relax to prevent ischemia in vana caval wall due to prolong pressure by balloon.

After a regular period of interval (may be few hours, such as 12-24 hours), only one balloon (alternatively) gets distended when the rest remain relax to prevent ischemia in vana caval wall due to prolong pressure by balloon.

The catheter has marking along its length to make the access safe and easy.

This catheter has a collar at its outer end to be fixed to the skin and subcutaneous tissue. This end of catheter is blind from where only the 5 channels exit.

The input channel passes through the center portion of the balloon and never gets blocked with the distension of any balloon and delivers blood at the same rate as of the output channel.

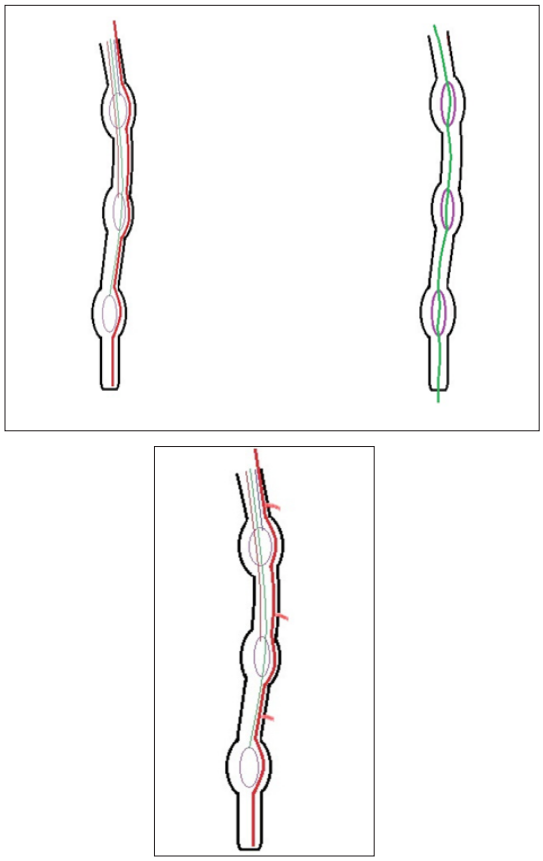


Figure8A. *Special venous catheter with 3 balloons, 3 inflation channels, 1 output channel (red) (in 1st figure) and the input channel (green) (in 2nd figure).*

This special venous catheter has 3 balloons, 3 inflation channels, 1 input (not here in this picture), and 1 output channel (red) with side pores (eyes). When one balloon gets distended output channel becomes blocked there and through the eye proximal to it, blood flow occurs.

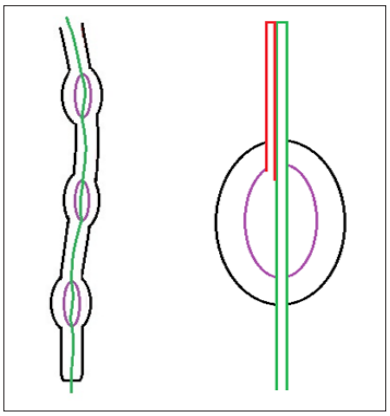


Figure8B. *Special venous catheter with 1 output channel (red) (in 1st figure) and the input channel (green) (in 2nd figure).*

This special venous catheter has an input channel within it (green); flow through it is not affected by distention of balloon by air.

Possible Complications

The application of this special equilibrium device has associated reasonable number potential complications with all other complications of central/ peripheral venous access.

The most potentially serious life threatening complications may be cardiac arrhythmia, ischemia of vana caval wall with prolong pressure by balloon and subsequent perforation.

Intensive Monitoring During and Following the Procedure

Intensive monitoring is required most of the time preferably through side channel 1 of input channel of the main device including:

- Continuous cardiac monitoring
- ABG analysis
- Respiratory monitoring etc.

Weaning

To prevent de-function mediated pulmonary dysfunction and alveolar collapse, pulmonary support,

mechanical inflation of lung, weaning etc. may be required.

Limitation

In this article, only crude concept of such application is going to be reported. But the suitable access or site of placement of such device to human body to have the optimal effect and other relevant are still in question. Proper planning of other such applications is still theoretical. To achieve success in practical setup, may need several modifications depending on further evidence based research on animal trial.

Conclusion

"Intravascular access based pulmonary support" is a new concept and is quite possible based on the principle of "The theory of relative stability" published in 2016. Moreover, organ support, dialysis machineries can be hugely upgraded by applying this fundamental basic rule. Further research in such relation is essential to rule out the subsequent benefits.

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