Circular circuits and low flow anesthesia

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Current situation of circular circuits in anaesthesia

- Problems in terminology:
  - Circuits:
    - with or without re-inhale,
    - partial or total re-inhale,
    - Open or semi-open circuits,
    - Close, semi-close, circuits,
    - circular circuits, intermittent circular circuits,
    - and so on…..
  - Flows:
    - Very high, maximum, high, intermediate, low, minimum, metabolic consumption, quantitative flows, and so on…
    - Many concepts poorly defined or even entirely mistaken concepts, and then repeated, creating confusion (leaks, > 2 lpm, 1 lpm, 0.5 lpm,…)


Circuits types

- **Open circuit**: All the critical care ventilators

- **Circular circuit**: Most of the anesthesia workstations:
  - We can used them well or wrong
  - If they are designed to reduce cost, we must know how to do it safely.
  - We must now what the main differences are between an open and a circular circuit, otherwise we are not going to understand how to do low flow anesthesia safely.
Open circuit

Flow generator:
Minute volume always equal to fresh gas flow

All the expiratory gases are wasted in each breath
Parts of any circular circuit

1. Y piece
2. Inspiratory limb
3. Expiratory limb
4. Uni-direction valves
5. Fresh gas flow
6. CO2 absorber (canister)
7. Vaporizer
9. Reservoir
10. APL valve.
11. Internal volume/compressive volume.
Does volume control mode always guarantee the volume in circular circuits?

Compressive volume compensation system: Are they all the same? Are they all equally effective?
6 months all patient; 6 Kg
Dx: hiatus hernia
Qx: laparoscopic Nissen.

Before
PNEUMOPERITONEUM

After
PNEUMOPERITONEUM
Before liver implant

Liver Tx:
- Pulmonary simulator
- Compliance = 0.6

After the liver implant
The circular system itself has more severe effects in children than in adults.

- **Machine internal Volume:**
  - **Compressive volume in the inspiratory period:** loss of tidal volume according to Boyle’s Law (1 ml/cm H₂O/l).
  - *For example:* a child weighing 10kg with an anaesthetic machine with a “compliance” of 5 ml/cmH₂O, when we set a tidal volume of 100 ml in volume control mode, if the pressure reaches 20 cmH₂O, the volume compressed and trapped inside the machine would be 100 ml, i.e. 100% of the volume set.
The circular system itself has more severe effects in children than in adults.

- **Machine internal Volume:**
  - **Compensation system** for compressive volume:
    - Estimate the extra-volume the machine must give multiplying machine compliance by the maximum pressure obtained. (this system have limitations). (Patient can be in troubles if the patient’s dynamic pulmonary compliance is less than the machine compliance)
  - With a flow-meter in the inspiratory limb: so what you set is what you delivery. The best option in general.
The circular system itself has more severe effects in children than in adults.

- **Patient breathing circuits**:
  - Watch out for circuit compliance because it will add to the machine’s compressive volume.
  - **Compensation system**: always by calculation of “compliance”. Some anaesthesia machine don’t have it.
  - **Disposable circuits**: Look out for the **accordion effect!!!**:
    - Adult circuit (22 mm): internal volume 0.5 l (you can find up to 2 l/cmH2O)
    - Paediatric (15 mm): internal volume 0.35 l (you can find up to 0.6 l/cmH2O)
    - Neonatal (10 mm): internal volume 0.18 l (up to 0.4 l/cmH2O)
The circular system itself has more severe effects in children than in adults.

- **Lost of effective tidal volume**
  - **Artificial dead Space**: Anything beyond the “Y” piece (the less the better). It generates a lot of problems blamed on the machine.

You lose 1 ml of tidal volume per ml of dead space you add.
Humidifiers, pneumotachometers, filters: Artificial Dead space effect

Infant 10 kg; 20 resp.rate
Vt = 80 ml; Vm = 1600 ml

\[ V_{\text{alveolar}} = V_t - V_D \]

\[ V_{\text{alveolar}} \times \text{RR} = (V_t \times \text{RR}) - (V_D \times \text{RR}) \]

Volume = 83 ml

Vm alveolar = 1600 ml - 1660 ml = 0 ml
Efficacy of the circuit: Fresh Gas Flow Utilization

Relationship between the volume of fresh gas that enters the lungs with respect to the entire volume of fresh gas that enters the circuit.

Efficacy

Coefficient of fresh gas utilization (FGU)

\[
\text{FGU} \, (\%) \, = \, \frac{\text{FGF}_{\text{inspired}}}{\text{FGF}_{\text{fresh}}}
\]
Efficacy

FGU = 1 (100%)

All the fresh gas (FGF) would go to the lungs

The excess gas (VE-FGF) eliminated through APL would be composed exclusively of exhaled gas
Flow generator performance: Insufflation power

The future of anesthesia ventilators

The past of anesthesia ventilators
Flow generators: Bellows, pistons, turbines, injectors.

- **first generation:** *Bellow*
  - It belongs to the pass: it should not use anymore
  - High compressive volume: it depends on the size of the bottle (1.5 l).
  - There is an interface between flow generator and flow delivery: the lowest peak flow and lowest inflation power

- **Second generation:** *Piston*
  - Low compressive volume because they finish the way in each breath
  - They reach high pressures when trying to overcome high resistances or low compliance. High insufflation power
  - During the recovery time of the piston it cannot generate flow: it is difficult for him to keep the PEEP constant if there are important patient leaks
Third generation flow generators: turbines, Injectors

**Turbine:**
- It provide high peak flow and quick changes in flow: ideal for compensating leaks (NIV) and to reduce “the speed of changes” (machine time constant)
- Insufflation power depends on the rpm: They must reach high pressures when they try to overcome high resistances or low compliance (ask for it)

**Injectors:**
- It provide high peak flow and high insufflation power
- It is expensive
Time-flow curve

Pressure limited Ventilation (PLV)

Pressure control Ventilation (PCV)

Pressure

Pset

PEEP

Flow

Volume

Insp.

Esp.

Time

Accredited Advanced Mechanical Ventilation Course for Anesthesiologists
1. overshoot: over inspiratory flow.
2. Low power of insufflation: not enough inspiratory flow
3. No decupling of FGF:
The anaesthesia workstation itself has more severe effects in children than in adults.

- **Leaks:** are very important in children (un-cuffed tube and LMA).
  - Passive reservoir (bags or bellows) when they are empty the machine stops ventilate the patient
  - We have to ask for active-never-ending reservoir (system to automatically compensate leaks)

- **Time constant / Speed of changes:** Time constant plus use rate of fresh gas flow (100%). (the faster the better)
Mixture process: exponential

Time constant

After 1 \( \tau \) the process is 63% complete
After 2 \( \tau \) the process is 86% complete
After 3 \( \tau \) the process is 95% complete
Time constant

Volume: 10 L
Flow: 1 L/min

Volume/Flow = 10 min = τ

1 τ = 10 min
( 63 % )

2 τ = 20 min
( 86 % )

3 τ = 30 min
( 95 % )
Time constant effect

**Fact:**
- Changes in gas composition are slow.

**Cause:**
- Big internal volume in relation to FGF.

**Effect:**
- Rapid changes in concentration are not effective.
- Ex.: Open, close the vaporizer.

**Management:**
- Increase FGF after each modification.
How to measure the time constant

Measure the internal volume: \( \tau = V + \frac{CRF}{FGF} \)

We don´t know

For clinical purposes:
Set FGF 1 L (or what you use to use) and set Sevo 1%

Measure the time needed to reach FI: 0.6 (p.ex: 8 min)

\( \tau \) (FGF = 1 L): 8 min
Flash Multimedia
Simulvent “Javierito”
CD
Traditional way of Low flow in anaesthesia

A are very simple and easy method to understand low flow anesthesia: like.........
Brody's formula:

$$VO_2 = 10 \times \text{peso}^{3/4} \text{ (ml/min)}$$
The two key questions are:

- What FiO2 and vaporizer % do we have to use?
- ¿How to calculate the minimum flow required?
**Pantalla de Monitorización de Vida**

**O2**
- **insp.** 31%
- **esp.** 27%

**N2O**
- **insp.** 67%
- **esp.** 67%

**Sev.**
- **insp.** 1.6%
- **esp.** 1.4%

**CAM**
- Edad 35
- **insp.** 1.4

**CAM**
- CAM 1.4

**EtCO2**
- 32 mmHg

**inCO2**
- 0 mmHg

**VM**
- 5.8

**VT**
- 541 µL

**frec.**
- 10/min

**Pico**
- 23

**PLAT**
- 17

**PEEP**
- 6 cmH2O

**Gas fresco**
- **O2** 35%
- Flujo 2.00 L/min

**Presión de trabajo (Pmax)**
- 25 mbar

**Vt**
- 600 µL

**frec.**
- 10/min

**Tinsp**
- 2.0 seg

**PPS**
- 10 mbar

**PEEP**
- 5 mbar

**Descripción del Monitor:**
- **Iniciar Volúmetro:** Ctrl + confirmar

**Valores recomendados:**
- **I:E = 1:2**
- **Trigger = 0.4**

**Valores:**
- **Pmax:** 25 mbar
- **Vt:** 600 µL
- **Freq.:** 10/min
- **Tinsp:** 2.0 seg
- **PPS:** 10 mbar
- **PEEP:** 5 mbar

**Nota:**
- (Valores de ajuste y configuración adicionales según requerimientos específicos.)
Effect of dilution of inspiratory gas

Fact:
- FI setting ≠ FI delivered.

Cause:
- Denitrogenation
- Oxigen and Anesthetic uptake
- N\textsubscript{2}O
### Effect on FiO₂

(Consumption N₂O = 0)

<table>
<thead>
<tr>
<th>%O₂</th>
<th>O₂ L/min</th>
<th>N₂O L/min</th>
<th>%FiO₂</th>
</tr>
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<tbody>
<tr>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
<td>23</td>
</tr>
<tr>
<td>33%</td>
<td>1.0</td>
<td>2.0</td>
<td>28.6</td>
</tr>
<tr>
<td>2.0</td>
<td>4.0</td>
<td>4.0</td>
<td>31</td>
</tr>
</tbody>
</table>
Effect of dilution of inspiratory gas

Effect:
- Fall in FiO2 and % in halogenated
- FiN2O increasing

Management:
- Previous denitrogenation (pre-intubation)
- Administration of high FiO2.
- Administration of high FGF at the onset.
Low flow anesthesia

**Semiclosed re-breathing system**

- Low Flow Anaesthesia
  - Fresh gas flow: 1.0 L/min
- Minimal Flow Anaesthesia
  - Fresh gas flow: 0.5 L/min

**Closed re-breathing system**

- Closed Circuit
  - Constant gas volume
- Quantitative anaesthesia with Closed Circuit
  - Constant gas volume and gas composition

**Definition:**

- Metabolic Flow Anaesthesia
  - Fresh gas flow according to consumption

Baum J. Narkosesysteme. Anaesthesist 1987; 36: 393-399
\[ V_{O_2} = 10 \times KG[kg]^{\frac{3}{4}} \]

\[ V_{N_2O} = 1000 \times t^{-\frac{1}{2}} \]

\[ \dot{V}_{AN} = f \times MAC \times \lambda_{BG} \times Q \times t^{-\frac{1}{2}} \]
Uptake of gases during inhalational anesthesia

- Low Flow Anästhesie
- Minimal Flow Anästhesie
- Closed circuit anesthesia

- $O_2$
- $N_2O$
- gas
Low Flow Anästhesie

Minimal Flow Anästhesie
Anesthesia induction

Premedication: as usual

Initial phase (pre-induction) Pre-oxygenation (5 min) spontaneous breathing:

\[ \text{FiO}_2 \ 100\% \ vs \ 75\% \]

Induction: as usual

Denitrogenation
Initial phase with high fresh gas flow (high uptake phase)

- FGF 4 lpm
- Oxygen/air = FiO2 40 %
- Oxygen/N2O = FiO2 35 %
- Isoflurane 2 %, Sevoflurane: 3 %, Desflurane: 5.0 - 6.0%
Low flow anesthesia: flow reduction

- **Low Flow anesthesia**
  - Initial high flow phase: 5 minutes
  - Flow reduction: FGF 1 lpm
  - Oxygen/air = FiO2 60%
  - Oxygen/N2O = FiO2 50%
  - Isoflurane: 2.0 %, Sevoflurane: 3.0 %, Desflurane: 5 %

- **Minimal Flow anesthesia**
  - Initial high flow phase: 10 minutes
  - Flow reduction: FGF 0.5 lpm
  - Oxygen/air = FiO2 100%
  - Oxygen/N2O = FiO2 90%
  - Isoflurane, Sevoflurane and Desflurane: $+ 1.0 \pm 0.5$ %
Low flow anesthesia – withdrawal:

- Anesthesia withdrawal

- Vaporizer can be closed 10 - 20 min before end of surgery

- Tray to go to spontaneous breathing (Pressure support)

- After the last stitch  FGF = 6 l/min:

  \[ \text{O}_2 = 100\% \text{ vs O}_2/\text{air} \quad \text{FiO}_2 = 70\% \]
How to do low flow anaesthesia in the future?

Just push the button !!!!

Auto-Control
¿Questions?

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