Pulsatile blood flow during cardiac surgery with extra-corporeal circulation

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and

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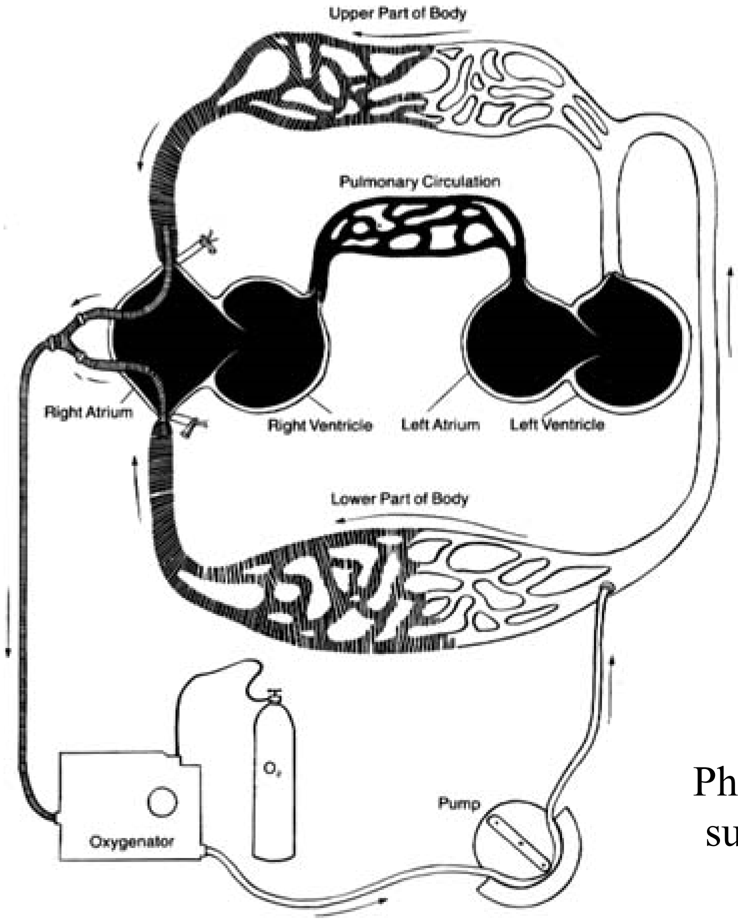
Nécessité d'une Circulation Extra Corporelle

Intervention sur les artères coronaires, sur les valves, malformations cardiaques congénitales, transplantation, …

- **Principe (très) simplifié:**

Le sang veineux est retiré du corps avant l'oreillette droite, va être filtré, oxygéné, puis ré-injecté à la personne au niveau de l'aorte; la pompe joue le rôle du cœur, l'oxygénateur celui des poumons.

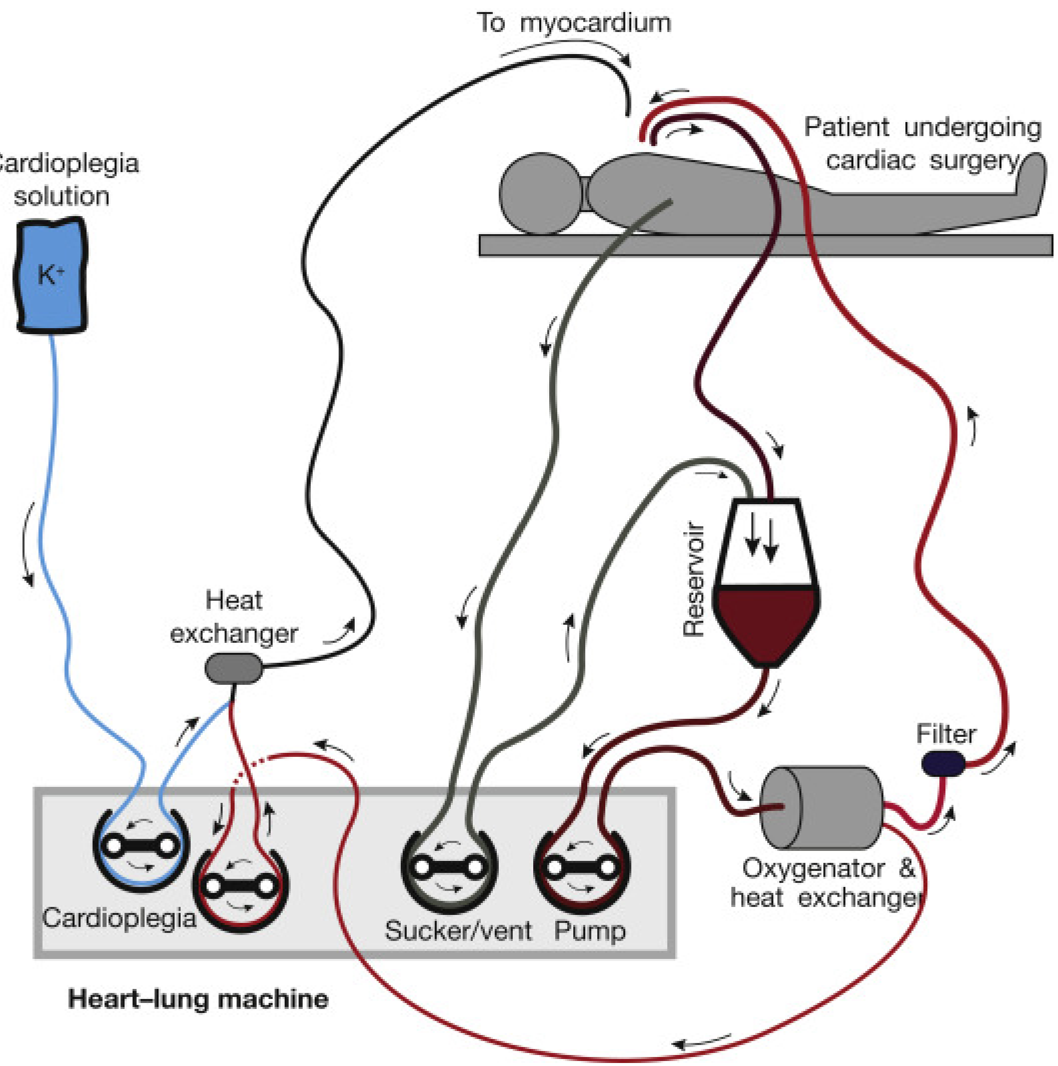


1ère chirurgie à cœur ouvert, utilisant une machine cœur-poumons: 06 Mai 1953, par Pr John Gibbon, à Philadelphie. (Opération réussie sur une jeune fille de 18 ans).

Les illustrations proviennent d'Internet

Schéma plus complet

- La solution de cardioplégie sert à stopper le battement cardiaque
- Le refroidissement diminue la demande en O_2 et ralentit le métabolisme.
- Tubulures en silicone ou PVC
- Sang hépariné, et dilué avec une solution isotonique
- Pompes péristaltiques ou centrifuges (moins d'hémolyse)
- Oxygénateurs à bulles, puis à membrane, fibres creuses (diminuent risque micro-bulles air)
- Filtres artériels



Les illustrations proviennent d'Internet

Les risques de la CEC

- SIRS: Systemic Inflammatory Response Syndrome
- Hémolyse, coagulation, caillots, bulles d'air, œdème (↘ drainage lymphatique),
- Risques techniques: panne, fuite, …
- Organes hypoperfusés (tube digestif, poumons, cerveau, …) ou hyperperfusés
- Risques liés au refroidissement et réchauffement,
- Risques liés à l'implantation des canules: percer ou déchirer des tissus voisins
- …

⟶ La question en débat:

Une circulation du sang pulsée lors de la CEC permet-elle de diminuer certains de ces risques par rapport à une circulation non pulsée?

Sachant que:
- créer un écoulement pulsé est plus difficile d'un point de vue pratique, plus coûteux
- l'écoulement pulsé aura des pics de vitesses ou de contraintes (donc augmente risque d'hémolyse ou de décrocher des débris de plaques d'athérome)

Bibliography:
advantage of a pulsatile flow for the microcirculation?

- Non- pulsatile flow: induces a progressive increase in systemic cardio-vascular resistance, reduces microcirculatory perfusion, vascular bed patency, endothelial function, decreases lymph flow, increases interstitial fluid retention, increases leukocytes activation and inflammation, alters renal function, increases incidence of bleeding or thrombosis, increases hemolysis, … (*N. V. Wright Thesis, 2014*)

- *Koning et al. (J. Appl. Physiol., 2012):* pulsatile flow during cardiopulmonary bypass preserves postoperative microcirculatory perfusion irrespective of systemic hemodynamics

- *Undar et al. (Artificial Organs, 1999):* pulsatile perfusion reduced the number of major complications … prevents vasoconstriction, … reduces systemic vascular resistance …

- *Ji and Undar (Perfusion , 2007):* excess energy is created by pulsatile flow and maintains perfusion through the microcirculation by ensuring capillary patency …. Pulsatile perfusion is more homogeneous, … reduces systemic inflammation …

- *Bozkurt et al. (J. Med. Biol. Eng. , 2016):* patients under pulsatile support exhibit less remodeling and functional changes in their vascular system compared to those under constant-flow support … long term organ function appeared to be preserved better …

Advantage of a pulsatile flow for the microcirculation? (2)

- *O'Neil et al. (Ann. Thorac. Surg. , 2012):* the implementation of pulsatile flow can better optimize microvascular perfusion and may lead to improved patient outcomes in high-risk cardiac surgical procedures requiring prolonged CPB time … less adherent leukocytes …
- *Undar et al. (Ann. Thor. Surg., 1999):* (with piglets). Pulsatile perfusion provides superior vital organs blood flow compared to non-pulsatile perfusion … (pulsatile roller pump) …
- *Son et al. (Int. J. Artif. Organs, 2005):* In cardiac arrest conditions, pulsatile extracorporeal circulation provides more blood flow, higher flow velocity, and less resistance to coronary artery than non-pulsatile
- *Elbers et al. (Jour. CardioThor. Vasc. Anesthesia , 2011):*no change in microcirculation during Pulsatile Perfusion compared with Non-Pulsatile …
  even in patients with large EEP differences, the surplus energy is still insufficient to propel pulsatility beyond the arterioles …
- *Isik et al. (Vasc. Surg., 1991):* Group I: CEC with non-pulsatile roller pump, and Group II: with a pulsatile device. No superiority of pulsatile flow was seen (many hematological parameters measured)
- *Sink et al. (The Annals Thorac. Surg., 1980):* Mongrel dogs, radioactive microspheres ; no difference between pulsatile or non-pulsatile perfusion as regards the renal function

Conclusions from bibliographic study

- Difficult to compare the studies: differences in patients selection, measurement techniques, experimental or clinical protocoles, …

- Pulsatility damping in the extra-corporeal flow path itself (oxygenator, cannulae, tubings, …) ?

- Pulsatility damping in the body (vessels, micro-vessels, …)

→ Is some pulsatility detectable in the microcirculation?
If yes, how to quantify this pulsatility?

Intravital microscopy? Laser Doppler? SDF (Sidestream Dark Field; *Elbers et al., 2011*)

Index Calculation: Perfused Vessel Density (PVD), Proportion of Perfused Vessels (PPV), Microvascular Flow Index (MFI) …

Some criteria related to the pressure wave shape ?

How to estimate pulsatility?

- Necessary to know pressure and flow rate waves: shape, amplitude, frequency, …
- Pulse Pressure: PP = Systolic Pressure – Diastolic Pressure
- Pulsatility Index: PI = (Systolic Vel. – Diastolic Vel.) / Mean Velocity
- Frequency Pulsatility Index: $PI_{freq} = \frac{\sum (A_i^2)}{A_0^2}$ (*N. V. Wright Thesis, 2014*)

  A_i = amplitude of each harmonic of the flow wave, and A_0 = amplitude of mean flow

- **Energy Equivalent P ressure** (***Shepard et al. , Arch. Surg., 1966***)

$$EEP = \frac{\int q(t)\, P(t)\, dt}{\int q(t)\, dt}$$

If non pulsatile flow, P(t) = Cste = P_{mean}, and q(t) = Cste., then EEP = P_{mean}

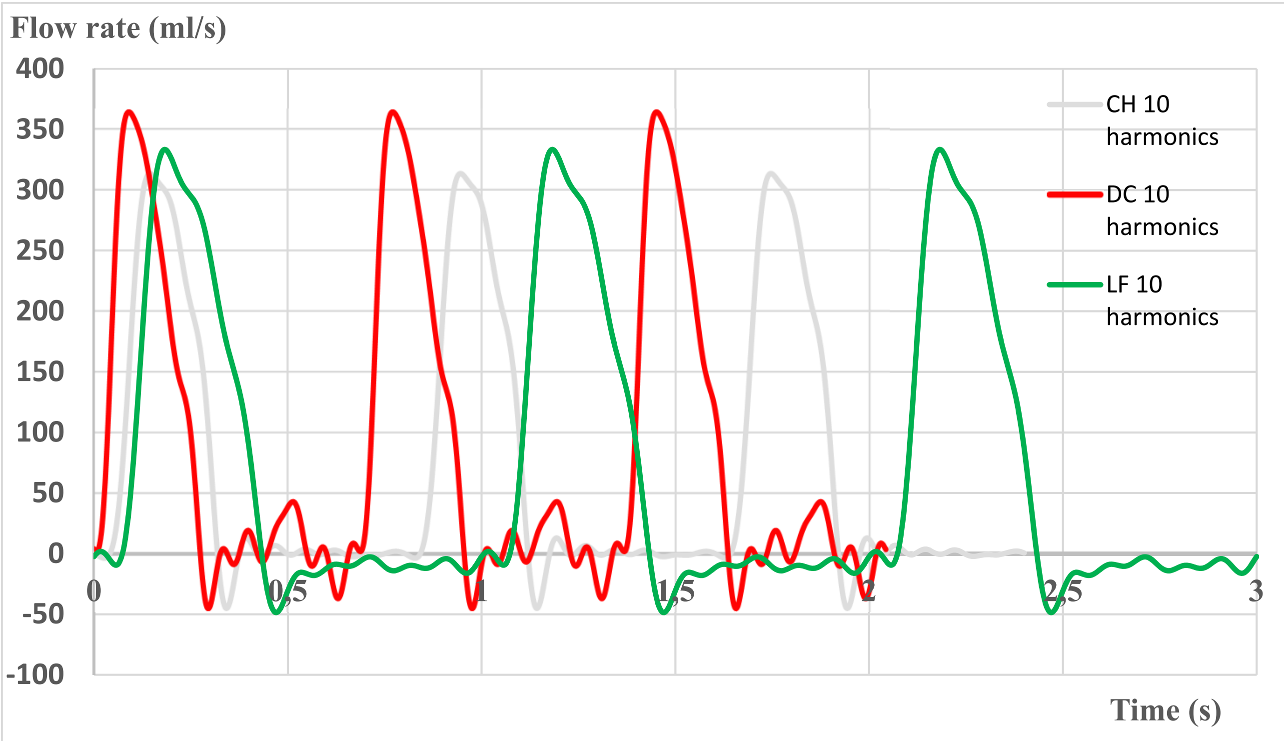
EEP homogeneous to (m^3 x Pa) / m^3, i.e. energy (N x m) per unit volume

Flow is considered pulsatile if EEP > 15 - 20 mmHg. Another index is then introduced:
SHE = Surplus Hemodynamic Energy = EEP - P_{mean}

Soucy et al. , The Jour. Heart Lung Transplantation, 2013
Travis et al., J. Thorac. CardioVasc. Surg., 2007

→ **Energy Equivalent Pressure calculation from aortic pressure and flow rate decomposition in harmonics**

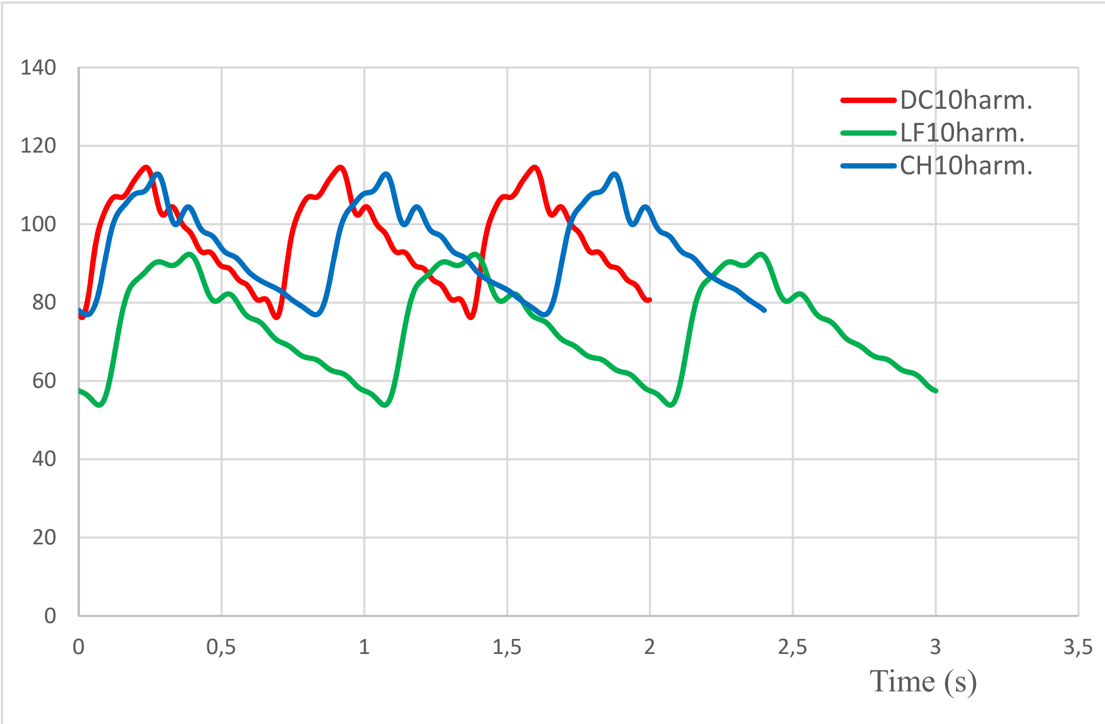
$$q(t) = q_0 + \sum_{k=1}^{10} q_k \sin(2\pi f\, k\, t + \theta_k)$$



Harmonics from : Patel et al., *Jour. Appl. Physiol.* 1965.

Aortic pressure (mmHg)

$$p(t) = p_0 + \sum_{i=1}^{10} p_i \sin(2\pi f\ i\ t + \emptyset_i)$$



Harmonics from : Patel et al., *Jour. Appl. Physiol.* 1965.

→ **Energy Equivalent Pressure calculation from aortic pressure and flow rate decomposition in harmonics**

$$q(t) = q_0 + \sum_{k=1}^{10} q_k \sin(2\pi f\, k\, t + \theta_k)$$

$$p(t) = p_0 + \sum_{i=1}^{10} p_i \sin(2\pi f\, i\, t + \emptyset_i)$$

→

$$EEP = \frac{\int q(t)\, P(t)\, dt}{\int q(t)\, dt}$$

$$EEP = p_0 + \frac{p_1}{2}\frac{q_1}{q_0}\cos(\emptyset_1 - \theta_1) + \cdots + \frac{p_j}{2}\frac{q_j}{q_0}\cos(\emptyset_j - \theta_j) + \cdots + \frac{p_{10}}{2}\frac{q_{10}}{q_0}\cos(\emptyset_{10} - \theta_{10})$$

→ **Result**: the surplus energy provided by pulsatile flow remains moderate (of order 10 mmHg). Sufficient to propel pulsatility beyond the arterioles?

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