Hemofiltration in Cardiac Patients
How to Choose the Parameters

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Abstract

Continuous veno-venous hemofiltration (CVVH) is a method of renal replacement therapy suitable for patients with cardiogenic shock and renal failure. Water and solute are removed from the blood by convection without causing hypotension. The tuning of hemofiltration parameters is mainly based on empirical rules of thumb and is aimed at efficient fluid and solute removal while keeping hemodynamic stability and preventing hemofilter clotting from exaggerated hemoconcentration at the hemofilter level. We have built an educational computer program that simulates the hemofiltration process and calculates the desirable relations between blood low through the hemofilter, the infusion rate and net negative fluid balance. This program also tries to predict the rate of urea and creatinine removal by the device according to the chosen parameters.

1. Introduction

Continuous veno-venous hemofiltration (CVVH) has gained wide acceptance within intensive care units as a method of renal replacement therapy [1,2]. Small and medium sized molecules are removed by convection and replacement fluid is infused, thus preserving hemodynamic stability. Hemofiltration is most suitable in patients with cardiogenic shock and renal failure, where conventional hemodialysis may cause hemodynamic instability. It may also be used in patients with severe heart failure complicated with edema, fluid accumulation and renal failure [3] and in patients after out of hospital cardiac arrest [4]. Hemofiltration has been shown to be effective in preventing the deterioration of renal function due to contrast-agent–induced nephropathy after coronary interventions [5]. The hemofiltration apparatus is a microprocessor-based device which controls pumping venous blood through a special hemofilter where the ultrafiltrate leaves the blood through special pores in the hemofilter. The device adds infusion fluid to the blood to exactly match the fluid loss in the hemofilter or enables a controlled preprogrammed negative fluid balance (The Edwards hemofiltration device). The mixed blood and infusion are then returned to the body. The tuning of hemofiltration parameters is mainly based on empirical rules of thumb, and is aimed at efficient fluid and solute removal while preserving hemodynamic stability, and preventing hemofilter clotting from exaggerated hemoconcentration at the hemofilter level. The aim of our present project was to build a computer program that will help to choose the right parameters in order to prevent hemofilter clotting and at the same time will try to predict changes in several blood constituents, mainly urea and creatinine, during hemofiltration.

2. Methods

Figure 1 demonstrates the hemofiltration process.

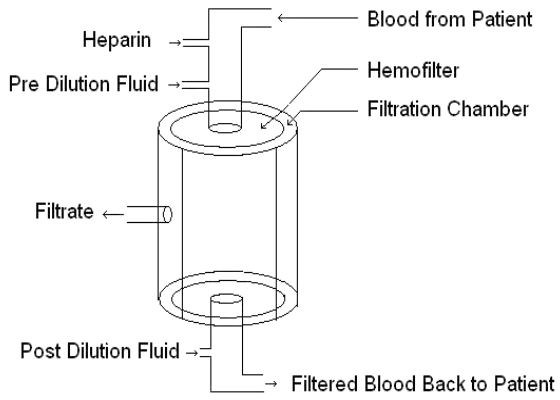

Figure 1. The hemofiltration Scheme

As blood is pumped through the hemofilter the filtrate moves to the filtration chamber and the hematocrit and protein concentration may rise to a point were the hemofilter may clot. In order to prevent extreme

blood concentration within the hemofilter, the blood is prediluted with replacement fluid and heparin. Three empirical criteria have been proposed for the assessment of desirable relationship between the blood flow and the ultrafiltration rate [6]:

1) the hematocrit at the end of the hemofilter should not exceed 0.5
2) Quf / Qbl <= 0.25 where Quf is the ultrafiltration rate and Qbl is blood flow.
3) Quf / Qpw <=0.5 where Qpw is the rate of flow of plasma water.

The hematocrit and protein concentration in the filter depends on the following parameters:
Qbl- the rate the blood is pumped out of the patient.
HCTin- the hematocrit of the patient
Quf- the rate of ultrafiltration.

The anticipated hematocrit level at the filter outlet is:

$$HCTout = HCTin \times Qbl / (Qbl - Quf)$$

The plasma water flow entering the hemofilter is:

$$Qpw = Qbl \times (1 - HCTin) \times (1 - 0.0107 \times TP)$$

Where:
Qpw is plasma water flow through the hemofilter
TP- total protein concentration of the patient
(1- 0.07 x TP) is a correction factor for plasma protein [6].
The first part of the present program uses these equations and the aforementioned criteria and calculates the desirable relationship between blood flow through the hemofilter and the rate of ultrafiltration.

The second part of the program tries to simulate the hemofiltration process and to predict the course of solute removal. CVVH is a pure ultrafiltration process and blood water solutes are removed by convection. The clearance of a solute may be calculated by the following formula [7]:

$$Cr = Quf \times S$$

Where:
Quf – the rate of ultrafilltration
Cr is clearance of a specific solute
S is the sieving coefficient which for Urea and creatinine approaches 1.0
If predilution is employed, the clearance formula changes:

$$Cr = Quf \times S \times [Qpw / (Qpw + Qpre)]$$

Where:
Quf – the rate of ultrafilltration
Cr is clearance of the specific solute
S is the sieving coefficient for the specific solute
Qpw- Plasma water flow
Qpre- the rate of predilution

According to this formula and an estimation of total body water, a first order difference equation was built, which simulates the clearance process.

3. Results

Figure 2-4 show the desirable relationship between blood flow and the rate of utrafiltration according to the restricting criteria.

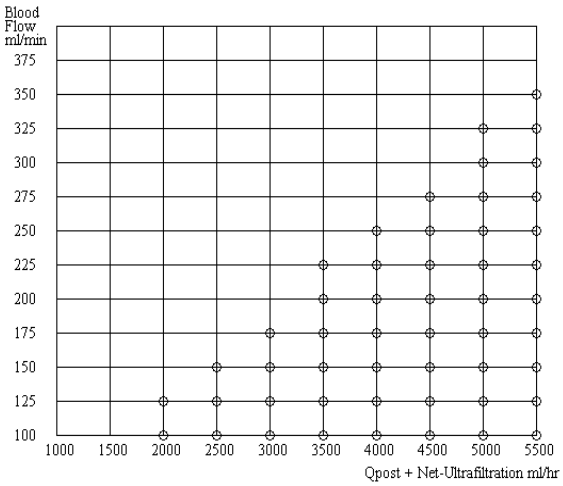

Figure 2. At the vertical axis blood flow in ml/min, at the horizontal axis ultrafiltration rate in ml/hr. The limiting criterion was Quf/Qb<0.25 and patient's hematocrit: HCT=0.39. The small black circles represent undesirable areas.

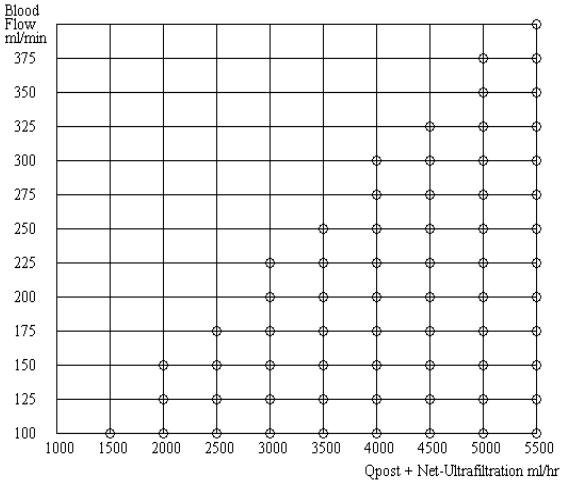

Figure 3. At the vertical axis blood flow in ml/min, at the horizontal axis ultrafiltration rate in ml/hr. The limiting criterion was HCTout < 0.5 and patient's hematocrit: HCT=0.39. The small black circles represent undesirable areas.

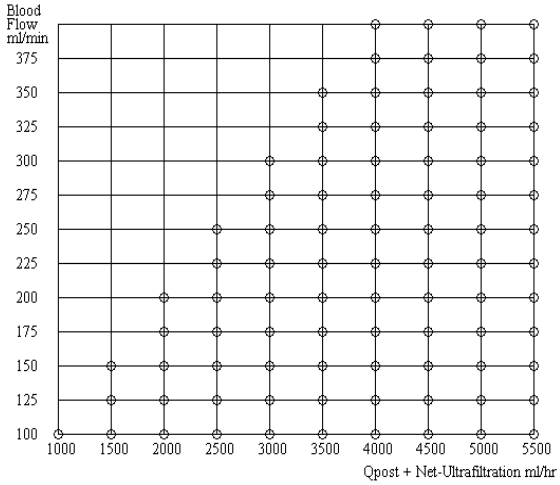

Figure 4. At the vertical axis blood flow in ml/min, at the horizontal axis ultrafiltration rate in ml/hr. The limiting criterion was HCTout < 0.5 and patient's hematocrit: HCT=0.42. The small black circles represent undesirable areas.

Figure 5 shows the model based calculated trajectories of creatinine decline according to ultrafiltration rates of 25, 35 and 45 ml/kg/hr.

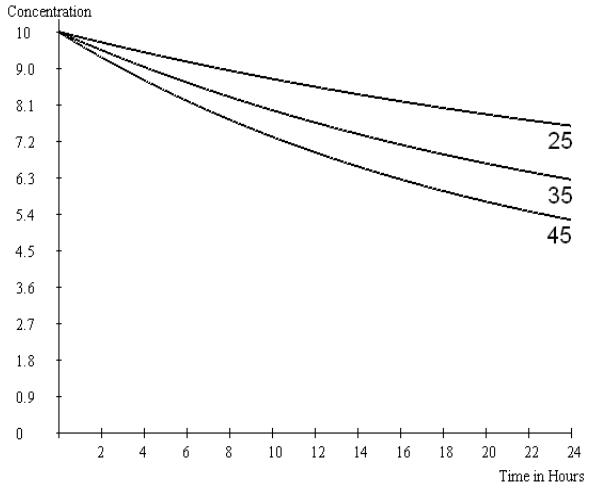

Figure 5. The anticipated timed creatinine level decline according to ultrafiltration rate in ml/kg/hr. At the vertical axis serum creatinine level in mg/dl, at the horizontal axis time in hours.

4. Discussion and conclusions

Although hemofiltration has already been used successfully in general intensive care units for the last few years, the tuning of the hemofiltration parameters is still empiric. The ratio between blood flow and ultrfiltration rate is determined according to criteria based on gathering experience with hemofilter performance and durability, and the fluid regimen is usually based on the results of clinical trials like the one by Ronco et al [1]. A frequent starting dose is 35ml/kg/min divided as 1/3 predilution and 2/3 post dilution. Following promising results of hemofiltration in a variety of cardiac conditions [3-5] cardiologists start to show interest in this technique. The basic concepts of hemofiltration are new to cardiologists who have to start thinking in "a nephrologic mind". This was the reason for this program to be built. The program easily enables the physician to choose the right parameters in order to keep hemofilter functionality. The ability to simulate the process of hemofiltration gives the clinician the opportunity to change the hemofiltration parameters on the computer, and gain intuitive feeling on the anticipated influence of these changes on the rate of solute removal from the body. Although very instructive, This program is only a preliminary necessary step. There is still much to be done in this very fascinating new area.

Acknowledgements

I would like to thank our outstanding staff of the coronary care unit at Laniado Hospital, physicians and nurses who managed to assimilate such a different and demanding technique within the timeframe of our general performance.

References

[1] Ronco C, Bellomo R, Hommel P, et al. Effects of different doses in continuous veno-venous hemofiltration on outcomes in acute renal failure: a prospective, randomized trial. Lancet 2000;355:26–30.

[2] Murray P, Hall J. Update in nonpulmonary critical care renal replacement therapy for acute renal failure. Am J Respir Crit Care Med 2000;162:777–781.

[3] Ultrafiltration versus intravenous diuretics for patients hospitalized for acute decompensated heart failure. Costanzo MF, Guglin ME, Saltzberg MT, Jessup ML, Bart BA, MD, Teerlink JR, Jaski BE, Fang JC, Feller ED, Haas GJ, Anderson AS, Schollmeyer MP, Sobotka PA, for the UNLOAD Trial Investigators. Journal of the American College of Cardiology 2007;49:675-683.

[4] High-volume hemofiltration after out-of-hospital cardiac arrest a randomized study. Laurent I, Adrie C, Vinsonneau C, Cariou A, Chiche JD, Ohanessian A, Spaulding C, Carli P, Dhainaut JF, Monchi M. Journal of the American College of Cardiology 2007; 46:432-437.

[5] The prevention of radiocontrast-agent– induced nephropathy by hemofiltration. Marenzi G, Marana I, Lauri G, Assanelli E, Grazi M, Campodonico J,

Trabattoni D, Fabbiocchi F, Piero Montorsi P, Bartorelli A. N Engl J Med 2003;349:1333-40.
[6] Colossi G, Frattini G. Quantitative analysis of convective dose in hemofiltration and hemodiafiltration: ‘‘Predilution’’ vs. ‘‘postdilution’’ reinfusion. Hemodialysis International 2007; 11:76–85.
[7] Clark WR, Turk JE, Kraus MA, Gao D. Dose determinants in continuous renal replaement therapy. Artificial Organs 2003; 27(9): 815-820.

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