Continuous Hemofiltration: Comparison and Indications of its Different Implementations

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Since 1977 and the article from Kramer et al., continuous hemofiltration (CHF) has known an increasing significance[1]. Compared with intermittent or continuous hemodialysis, this procedure appears to contribute a great deal for many authors. Thus, its use is progressively applicable to more patients and to new indications. However, most of its clinical indications depend on its basic principles, its modes of implementation and some other significant aspects.

Principles of hemofiltration

Like hemodialysis (HD), continuous hemofiltration diverts patient's blood onto a hemofilter: a membrane across which material movements are achieved by convection[2]. The main difference between these two renal supply procedures consists of pressure regimen on the two membrane sides. HD requires similar hydrostatic pressures with a trans-membrane osmotic gradient that favors diffusion. In CHF, on the contrary, a net transmembrane hydrostatic pressure gradient is necessary for convection to be favored. Small and medium weight molecules sustain a convective transport. As circuit resistances are quite constant the main determinants of UF rate (UF) are hemofilter surface and blood flow.

Modes of implementation

Arteriovenous access

Continuous Arterio Venous hemofiltration (CAVH) is the easier procedure to be performed. Patient's arterial blood pressure provides energy from a catheter inserted into an artery to deliver blood to the hemofilter. It is returned to the patient by a venous line. Spontaneous blood flow is about 80 ml/min^{-1} for normal mean blood pressure. Under these conditions, ultrafiltrate rate appears to be sufficient (> 400 ml/h^{-1}) to result in total renal supply if there is a continuous and early use[2]. Recently, new hemofilters with internal configuration and resistances adapted to arteriovenous procedure have been designed and marketed[3]. Blood pressure is high enough to allow a good circulation of blood into the circuit. The major inconvenient of this technique is to require two vascular accesses including a large arterial catheterization with its well-known specific complications (embolism, thrombosis, aneurysm, fistula, hemorrhage...).

Veno venous access

Continuous Veno Venous Hemofiltration (CVVH) derives and returns venous blood with a pump (Fig. 1). Imposed flow defines ultrafiltration pressure and thus amounts of ultrafiltrate that is produced. Detection alarms are required since air embolism or hemorrhage are possible. This technique can use a single large double lumen venous catheter.

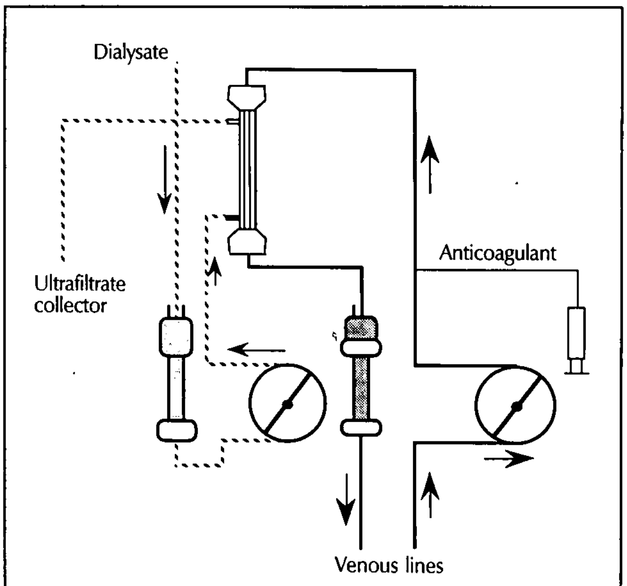

Fig. 1.—Description of a CVVHd circuit.

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Additional dialysis

The major improvement of late years appears to be the possibility to achieve additional continuous dialysis, using the hemofilter to perform movements by diffusion in addition to transports by convection. There is a low flow circulation of fluid with low flow dialysate (0.5 to 4 $l.h^{-1}$) in the ultrafiltrate collection chamber. These techniques are named CAVHD, CVVHD or «hemodiafiltration».

Significant aspects of continuous hemofiltration procedures

Ultrafiltrate substitution

Total daily ultrafiltrate volume can rise up to 20 liters that should be replaced according to patient status and needs. Solute electro-neutrality is usually provided by acetate, lactate or bicarbonate. Substitution solute also replaces the unavoidable losses due to UF such as dextrose, calcium, bicarbonate and phosphate.

Since large water volumes are daily turned over, physical examination and appropriate laboratory data must be reviewed frequently to guide carefully fluid management. Several methods of automatic fluid substitution are developing currently to avoid fluctuations of fluid balance over time.

Anticoagulation

CHF circuit requires anticoagulation to avoid activation of clotting factors that are concentrated in contact with the device at the time of ultrafiltration. Continuous feature of CHF makes a gradual process of thrombosis inevitable[4]. Profit of substantial coagulation and risk should be weighed up, especially in CAVH(D). Continuously delivered heparin is the most common. Doses depend on several factors according to patient and device. Therefore many methods have been assessed including low molecular weight heparin [4,5], prostacyclin[4], citrate[6] or protease inhibitors[7].

Other important aspects

Numerous nutrients[8] and drugs are widely remove with UF. This phenomenon is clearly more important than with HD. This problem is emphasized by the continuous use of these therapies. Dextrose is easily ultrafiltrated and adequate dextrose amounts assessed by measurement in UF are to be administered. Circulating amino acid ultrafiltration is very variable but remains negligible from a practical point of view considering required needs in most ICU's patients. Fat emulsions do not seem to be ultrafiltrated but have been held responsible for permeability reduction. However, with better laboratory data control, CHF allows to achieve parenteral or enteral nutrition with freedom to administer large water, nitrogen or caloric amounts. This facility is not so easy to achieve with HD.

Most therapeutic drugs should be permeable through CHF membranes. Nevertheless the protein-bound fraction stops this leak because only is the unbound drug in plasma water «ultrafilterable»[9]. Drug concentration measurement in plasma water practically allows quick dose adaptation, when it is available. Priority should be given to the use of hemofilters that have been the most studied for therapeutic agents' filtration[10]. However, CHF makes possible administration of drugs with large sodium load or with large water volume whatever the patient's water and sodium status are.

Continuous extracorporeal circulation at room temperature leads to blood cooling. Blood re-warming appears to be necessary. Substitution solute warming seems to be the best method. It allows compensation of both convective caloric ultrafiltrate loss and temperature decrease following both radiation and conduction in blood circuit. Hypothermia has been suggested to be a factor of good cardiovascular tolerance of dialysis[11]. However, it avoids to put body temperature modifications down to septic events.

Continuous hemofiltration demands constant monitoring of both device and patient. Continuous nature of CHF increases staff workload. Ratio of one nurse to one patient must be respected. Substantial water and electrolyte movements require experienced staff. Infection remains one of the most important risk of this method. Systematic blood cultures are recommended. Device cost in CHF is paltry. Therefore HD and CHF are quite similar in cost. Actual CHF cost and HD cost as well, should be considered including staff workload assessment.

Results

Renal replacement

Continuous hemofiltration is the most effective «diuretic» method: it directly removes plasma water. This is a very attractive therapeutic property. Recovery of water equilibrium requires in most patients only a few hours. CHF is more efficient than HD for middle and high weight molecules' removal. At the opposite, BUN is not eliminated as well as with same HD duration. When movements reach 12 to 15 liters a day, total renal supply should be achieved by CHF. Plasma electrolytes are ultrafiltrated with concentrations close to plasma ones. Removed amounts thus depend on plasma concentrations that are low for potassium and large for sodium, chloride or bicarbonates. Consequently, CHF does not allow direct hyperkalemia correction as quickly as HD does. This might be an incovenient of CHF in ICUs. However, sodium and water overload induced by some large amounts of bicarbonate are easily reversed with CHF. Normal potassium supplies become soon necessary.

CAVH allows to increase the clearance of molecules with low molecular weight with no change on hemodynamic stability. For example urea clearance increases from 15 $ml.min^{-1}$ to 30 $ml.min^{-1}$ with an additional dialysate flow of 33 $ml.min^{-1}$ [12].

Tolerance

In the literature, superiority of CHF over HD has been emphasized concerning cardio-circulatory tolerance in spite of equal or larger water removal[11, 13]. Lack of movement induced by osmotic variations between intra and extra-cellular compartments could be the explanation for this tolerance[14-16]. Ultrafiltrate is produced from vascular space in CHF but it is very quickly replaced by both substitution fluid and convective movement from interstitial space. The exact clinical importance and the responsibility in cardiovascular tolerance of catecholamines removal under CHF is uncertain and should be studied further[17, 18]. Even if hemofiltration is continuously used, its biological tolerance appears to be good (Fig. 2). Complement activation seems slight with the new devices[19]. Thrombocytopenia is frequent but mild. It becomes an actual problem in ICU's patients with severe sepsis-induced thrombocytopenia[2].

Substances removal

Removal of substances that are not physiologically eliminated by kidney is of interest especially in multiple organ failure (MOF) in which numerous pathological mediators have been invoked. Usual association of renal deficiency with septic states, MOF or acute respiratory distress syndrome (ARDS) is an interesting model for studying material removal during renal supply. Even if the material removal is likely to be a reality, their exact identification remains unknown[20-24]. Cytokines as Tumor Necrosis Factor (TNF) or Interleukins (ILs) are not eliminated in the UF. This is almost due to their molecular weight that avoids their passage through the hemofilter. Nevertheless, an absorption of these substances along the membrane, leading to a decrease in their blood concentrations seems to be possible[25]. The clinical effects of this removal are unknown. With CHF, most of substances with molecular weight under 6,000 daltons could potentially be removed. This removal can be achieved either by ultrafiltration or by binding these molecules to the hemofilter membrane. Likewise it seems that gastrin can be removed very quickly by CHF that might be of contribution to medical treatment of stress gastro-duodenal hemorrhage[26].

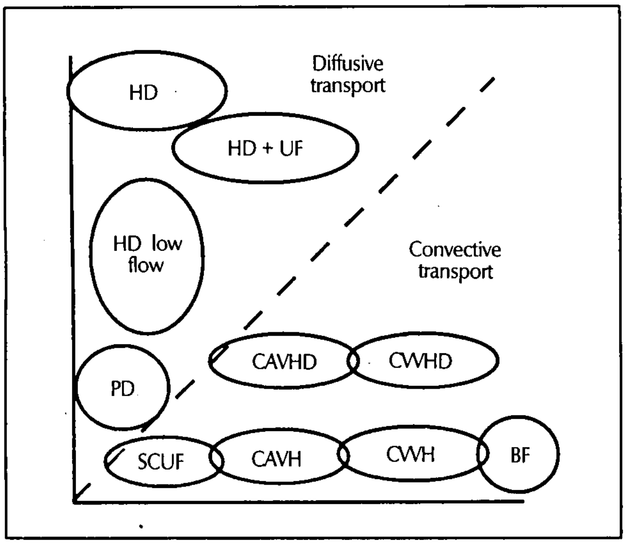

Fig. 2.—«Mapping» of the different renal supply techniques according to respective parts of diffusion and convection. HD: Hemodialysis, PD: Peritoneal Dialysis, CAVH(D): Continuous Arteriovenous Hemofiltration + (Dialysis), CVVH(D): Continuous VenoVenous Hemofiltration + (Dialysis), SCUF: Slow Continuous Ultrafiltration, BF: Biofiltration.

Indications of different CHF methods

Every renal supply technique is able to reach, easily or not, a correct level of renal supply. Furthermore, the choice in various techniques focuses on additional goals to achieve. Patient's status and pathology should turn towards the choice of the technique.

Hemodialysis versus hemofiltration

Choosing CHF rather than HD usually rests upon its better cardiovascular tolerance.

Water elimination

Facility to remove water and electrolytes, associated with a high circulatory tolerance is convenient in numerous ICU's situations. The therapeutic goal of the clinician under these conditions is not at all to normalize the patient weight but also to fight against a pathological distribution of water into the various body compartments. Restoration of water and electrolyte balance to limit interstitial edema, particularly pulmonary hyper-hydratation has been suggested[27]. In some situations a large amount of water withdrawal can dramatically improve blood oxygenation[28].

CAVH versus CVVH

CAVH is generally appreciated for its simplicity. This technique offers the possibility to manage ARF under many circumstances in which a dedicated device is not available. This explains some good clinical results in extra-hospital circumstances (earthquakes, wars...). Introduction of low flow dialysis has clearly modified the interest of ICU's clinicians in this technique.

Substances removal

Some complementary CHF properties could soon become good reasons to prefer CHF in ICU's septic patients.

Currently, there is some evidence that CHF removes some substances from blood deleterious on heart inotropism [24], pulmonary and ventilatory functions [23]. These results have been drawn in animal septic models. However, the assessment of the usefulness of this features should be obtained in clinical situations. Even if some clinical studies have suggested efficiency of CHF on survival [20] or on renal recovery [21], the respective responsability of toxin removal and hyper-hydratation correction need further investigations [22, 28]. Furthermore, it remains unknown whether the use of a continuous therapy as CHF, which increases nurse's workload and could offer a wide incidence to septic complications, can actually be compensated by some «in-vitro» beneficial effects that have been pointed out.

However, even though hemofiltration is chosen rather than hemodialysis for its specific properties, its technique should be optimized: It seems that elimination of «mediators» is parallel to ultrafiltrate flow [20, 21]. This fact favors CVVH rather than CAVH. CVVH regularly offers the highest UF rate. Likewise, the hemofilter area should be maximized to increase UF flow. Even if a surface of 0.5 to 1 m^2 is usually enough to rapidly achieve renal suppleance, surfaces over 1 m^2 could soon become a usual standard to increase material removal.

Conclusion

Hemofiltration is a well known renal suppleance technique that can be performed with several techniques. An improvement of their performances has recently been achieved using new device designs and increased hemofilter surfaces. Major inconvenient of CHF over hemodialysis, as the necessity of a continuous therapy, high nurse workload, difficulty to achieve a permanently adequate fluid balance, erratic drug's elimination are counterbalanced by the large water removal that it allows. Elimination of toxic substances from plasma could lead in the future to prefer these techniques under certain intensive care conditions.

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