Monitoring of blood volume during haemodialysis treatment of acute renal and multiple organ failures

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Abstract The assessment of the level of hydration in the intravascular fluid compartment in acute renal failure (ARF) and multiple organ failure (MOF) is of utmost importance. However, the data on monitoring of blood volume in these diseases and especially during haemodialysis treatment are lacking. This article summarizing the experience of monitoring of blood volume in chronic haemodialysis suggests that the application of such monitoring will contribute to better results in haemodialysis treatment of ARF and MOF.

Key words: acute renal failure; blood volume; fluid state; haemodialysis; multiple organ failure

Introduction

Restoration and maintenance of adequate circulating blood volume is an essential goal in the management of critically ill patients. In general, determination of central venous pressure and pulmonary capillary wedge pressure obtained invasively has been regarded as relatively good indicators of the hydration state in the intravascular compartment. Neither of these parameters directly measures absolute blood volume, but reflects its adequacy from secondary haemodynamic reactions and more recently their use has been criticized [1]. At the same time, measurements of blood volume using tracer dilution techniques have been established as relatively accurate and reproducible [2]. However, such techniques are time consuming, cannot be repeated frequently, and usually involve exposure to radioactivity. Furthermore the tracers are easily removed by dialysis and for all these reasons are not applicable to continuous monitoring of dialysis procedures. Such reasons may explain the scarcity of data on blood volume and the fluid state in acute renal failure (ARF) and multiple organ failure (MOF).

Fluid state in ARF and MOF and clinical effects of fluid removal

Fluid retention is one of the most common features of ARF, and frequently leads to serious complications such as cardiac failure and respiratory failure [3]. In general, fluid overload has been regarded as a poor prognostic sign in postoperative critically ill patients [4]. According to Rosenberg [5], the extracellular volume of patients with post-traumatic ARF may be 1.5 times greater than normal. In some cases the fluid excess, based on the daily intake/excretion, has been found to be as high as 11 litres. [3]

Thus, maintenance of an adequate fluid state is related to the removal of a large amount of fluid. Although only a limited number of well-designed conclusive studies have been performed on whether continuous therapies (CAVHF, CVVHF etc.) are better than intermittent haemodialysis, it is obvious that an adequate fluid state would more easily be attained by the use of continuous rather than intermittent treatment. Moreover, because of the intermittent nature of conventional haemodialysis, fluid excess accumulates almost uncontrollably during the interdialysis period. The removal of large amounts of fluid during a short time is hindered by hypotension and the optimal fluid state in many cases is not achieved. This results in persistent oedema as well as cardiac and respiratory complications. Intradialytic hypotension, which occurs in almost one-third of the procedures, may cause acute life-threatening complications such as cardiac arrest [6]. Variations of intradialysis blood pressure in such patients may also have a negative effect on cerebral perfusion [7].

Furthermore, Conger [8] drew attention to the fact that the unstable circulation during haemodialysis may have a negative effect on endogenous renal function. He speculated that the intradialysis decline in renal blood flow might cause tubular ischaemia and that the intradialysis hypotension might delay the recovery from postischaemic ARF. In fact, no recovery of renal function was observed in the series of patients with ARF and MOF in whom haemodialysis sessions were...
associated with frequent episodes of intradialysis hypotension [9].

At the same time, avoiding drastic changes in fluid state by combining isovolaemic intermittent haemodialysis with CAVHF [10] has proved to be favourable for recovery of renal function and the total survival rate.

As the depletion in blood volume may continue up to 16 h after a haemodialysis session [11], one could assume that the negative effects of hypovolaemia on systemic and renal haemodynamics may even be long—lasting after uncontrolled fluid removal during intermittent haemodialysis. Moreover, the ability to restore blood volume by mobilizing fluid from the interstitial compartment may be depressed because of derangements in the protein balance in ARF and MOF.

Obviously, the excessive and incorrect removal of fluid during intermittent haemodialysis treatment of ARF and MOF has both acute and long—lasting negative effects on several vital functions due to hypotension.

**Hypovolaemic hypotension**

Among the factors contributing to hypotension in haemodialysis treatment of ARF and MOF, hypovolaemia was considered to be a principal one [12]. The removal of fluid during haemodialysis leads to reductions in venous return and cardiac output. For a short time, a stable blood pressure is maintained by activating the sympathetic nervous system, thereby causing tachycardia and vasoconstriction. When blood volume and venous return have reached a critical minimum and the compensatory mechanisms are exhausted, hypotension suddenly occurs. This critical minimum blood volume is variable and depends on the patient's characteristics such as the relationship between cardiac performance and the sympathetic threshold.

Kim et al. [13] has found that an intradialytic reduction in blood pressure occurs in 80% of the patients on chronic maintenance haemodialysis, with an absolute predialysis blood volume of less than 50 ml/kg body weight. However, since during haemodialysis blood volume is continuously replenished with fluid from the interstitial compartment, the rate of refilling must also be taken into consideration.

**Intravascular refilling**

Fluid removal during haemodialysis disturbs the equilibrium between the intravascular compartment, i.e. blood volume and other fluid compartments (interstitial and intracellular). Fluid exchange across the vessel walls is controlled by the interaction of hydrostatic and oncotic driving forces [14].

The refilling rate depends on the following factors:

*Individual state of hydration.* When the interstitial space is overloaded, the refilling rate is greater than the rate in nearly normal or depleted fluid states [15]. Some data show the relationship between the reduction in blood volume per litre of ultrafiltrate and the level of fluid overload is exponential [16].

**Ultrafiltration rate.** The refilling rate increases exponentially with the ultrafiltration rate, according to Mann et al. [16]. We found completely different blood volume responses on two occasions (Figure 1), but at identical levels of hydration after using high and low ultrafiltration rates [17]. However, approaching a given lower level of hydration, the refilling rate does not increase further [18].

**Dialysate fluid content.** A linear relationship exists between the changes in sodium concentration and blood volume [16]. An increased dialysate sodium concentration is related to improved refilling, while a low sodium leads to decrease in blood volume [16, 19]. Refilling is reported to be better during haemodialysis with bicarbonate than with acetate dialysate [20, 21].

**The total protein balance** [22, 23], as well as capillary permeability [23], are also involved in the regulation of the refilling process. These factors may be negatively influenced in ARF and MOF in patients with malnutrition, sepsis, liver disease, diabetes mellitus [24], and thermal injury [25].

**Continuous monitoring of blood volume changes**

Continuous monitoring of blood volume changes is performed non—invasively and is based on different principles [26—34]. Experience with such monitoring hitherto has been limited to chronic maintenance haemodialysis.

De Vries et al. [35] observed a remarkable difference between the slopes of the decrease in blood volume during haemodialysis sessions, which were, or were not, complicated by hypotension. Using on—line optical reflection method for monitoring of blood volume changes and low—frequency conductivity technique for assessment of the level of hydration in extracellular space Bogaard et al. [36] found more profound decrease in blood volume among the underhydrated than in normo— and overhydrated chronic haemodialysis patients. The hypotensive episodes occurred more frequently in the underhydrated group.

An attempt to reduce the intradialytic morbidity by adjusting the ultrafiltration rate to the detected critical decrease in blood volume monitored by haematoctrit was made by Steuer et al. [37] They suggested that some symptoms related to volume depletion such as cramps, dizziness and nausea may occur at the same continuously monitored haematocrit. Previously this group reported a similar relationship between hypotension and decline in blood volume [38] assuming that a patient's specific haematocrit threshold is predictive of a critical blood volume, below which certain patients become hypotensive.

The individual blood volume response has been classified into various types of refilling [39]. An attempt to assess the integral fluid state by applying continuous
monitoring of blood volume changes was made recently by Lopot et al. [40]. He classified the decline of blood volume into groups, since the type of blood volume response was related to the degree of hydration assessed by impedance spectroscopy. The absence of any large decrease in blood volume was ascribed to overhydration, while the steeper blood volume slope was related to hypovolaemia. Hence continuous monitoring of blood volume during haemodialysis may be used to reduce the episodes of hypovolaemia related hypotension and complications, and to adjust the haemodialysis treatment according to the individual blood volume response. It can also be used in automatically controlled procedures. An automatic control system consisting of such a monitor has been employed to adjust the infusion rate of the substitution fluid during haemofiltration [32]. The infusion rate has been adjusted according to pretreatment—defined changes in blood volume and the desired levels were attained at the end of the procedure. Since the early stage of the continuous monitoring of blood volume changes, Schallenberg et al. proposed a method for assessing the absolute blood volume [30]. However, the experiments done subsequently [35, 41] hardly convince us that this method could be applied routinely. Moreover, we found no agreement between that measured with 131 I—labelled albumin and that predicted by non—invasive monitoring [42].

The complexity of interactions with the other compartments which affect blood volume during haemodialysis is the reason that the continuous monitoring of blood volume changes alone is not a relevant method for assessing the global fluid state. This assessment has been obtained by combining this monitoring with other tools, mainly multifrequency bioimpedance [36, 40, 43, 44].

Limitations

Continuous monitoring of blood volume changes is based on the assumption that the markers of the monitoring (haematocrit, haemoglobin, or total protein) do not leave the intravascular compartment and that red blood cells do not greatly change their number and volume throughout the haemodialysis session. Therefore one must take into account a possible influence of the altered osmotic gradients during haemodialysis [45], and as well as the effect of the intravenous infusions.

As the haemodialysis treatment of ARF and MOF is mainly performed via intravenous catheters, the impact of recirculation, which is common in this kind of vascular access, must also be considered [46].

In conclusion, although it is difficult to extrapolate the experience of continuous monitoring of blood volume changes from chronic haemodialysis to the treatment of ARF and MOF, and also the above—mentioned limiting factors, this is a promising method since it is easily and non—invasively performed and is relatively reliable. Its application could make intermittent haemodialysis treatment of ARF and MOF more physiological. The negative effects of excessive and inappropriately rapid fluid removal may be corrected by individualizing the duration of the session, ultrafiltration therapy, and dialysate sodium concentration (profiling) according to the specific blood volume response and patient’s clinical state.

References

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